University of Glasgow

College of Science & Engineering

FAST MOVING NEUTRONS, GRAPHITE MODERATORS AND RADIOACTIVE CLOUDS: AN ANT ACCOUNT OF THE CHERNOBYL ACCIDENT'S RISKY NETWORK

Ross MacGill

Thesis Submitted for the Degree of doctor in Human Geography (PhD)

University of Glasgow

College of Science and Engineering

School of Geographical and Earth Sciences

September 2016

Declaration

I declare that the thesis, except where acknowledged to others, is the result of my work and does not include work forming part of a thesis presented successfully for another degree at the University of Glasgow or any other institution.

………………………………

Ross MacGill

September 2016

Do you even praise the sun?

Table of Contents

List of Figures

Abstract

This research seeks to understand the Chernobyl accident at the material level and this is achieved through a sustained engagement and use of Latour's Actor-Network Theory. The primary research question asks how has the accident travelled through various worlds: impacting upon them, reorienting their structure, and at times, creating new nuclear worlds in its wake. The ambiguous nature of the question is designed to allow the research to approach the expansive topic from several angles, thus accounting for the very real material spread radioactive fallout and, crucially, the material action engendered by the agency of RBMK no4, the central actant in the network in question. The nature of this work is quasi-scientific; that is, the majority of the empirical data is the discourses of the 'hard sciences', the disciplines tasked with understanding and mitigating one of the worst accidents the world has ever witnessed, and safeguarding against another similar occurrence. The reassembling of RBMK no4's network, and its travels, hence 'renders visible' the lessons learnt by the nuclear industry in the wake of the event of April 1986. The spectre of Chernobyl has loomed over the industry for 3 decades. This research attempts to create a pragmatic context. It is not interested in the epistemological 'sensationalist' representations of the accident. Instead it embraces the complex intricacies of the physics, engineering and radiological sciences – the very essence of the materiality of RBMK no4, and its risky network.

Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning. (Winston Churchill)

There he goes. One of God's own prototypes. A high-powered mutant of some kind never even considered for mass production. Too weird to live, and too rare to die. (Hunter S Thompson)

I have always quite enjoyed writing these opening statements, they feel like the pleasant reward after a job well done – the final chance to be dually thankful and whimsical after an odyssey of serious network reassembling.

As I sit here on a Tuesday afternoon, the realisation that I have actually finished this thing hasn't quite sunk it. Thus, I shall turn to words of gratitude, before attempting some poignant statement about this process, my work, and an ill faded nuclear power station in north Ukraine.

First and foremost, I want to thank my parents for their eternal support throughout my thirty revolutions around our friendly solar system fusion furnace. I would not be in this position, nor the man I have eventually grown into, without them. Next up is my Polish lioness, Monika. She is the best thing that ever happened to me and her love and support has kept me on track and sane during this process. A section expressing gratitude would not be complete without mentioning 'the Dream Team': Dr Ian Shaw and Professor Chris Philo. We made it boys, with the aid of Mr Latour we took the materiality of RBMK no4 seriously and learnt a lot along the way. I will forever be thankful for your attention, guidance and friendship throughout this enjoyable ride.

Finally, I can't forget about CD Projekt Red. During the last 4 years, this little upstart Polish development studio raised the bar of gaming quality to heights that I had only dreamt of, and subsequently allowed this Glaswegian geek to walk the path of a Witcher – an indispensable form of escapism during this long and challenging journey. I salute you Geralt of Rivia, and you shall never be forgotten, Vesemir of Kaer Morhen.

I digress.

Doctoral training is privilege awarded to the dedicated, intellectually gifted and tenaciously motivated. For the lucky few, funding is gained to research a phenomena close to their personal interests and/or passions. I am a member of this group. As I detail in chapter 1, Chernobyl, and by extension, nuclear technology, has fascinated me for years. This PhD has allowed me to indulge this obsession to the Nth degree. It is not a traditional human geographical or social science piece of research, as it deals, almost exclusively, with the discourses of the 'hard sciences'. The disciplines tasks with understanding, rectifying and mitigating one of the worst accidents our little blue space ship has ever witnessed.

It is a ruthlessly pragmatic piece of work. It is not attempting to claim that the accident of 1986 was anything else other than horrific, but it takes seriously the materiality of the event, the nuclear nonhuman of RBMK no4, and the science of its fallout, in an attempt to create an account that is devoid of 'sensationalist' representations. The network reassembled within allows the reader to make up their own mind, or, at the very least, provide them with information to make a more informed opinion of impacts of the Chernobyl accident.

I am an ANT scholar of nuclear risk and technology, and this is my account of how the agency of a nonhuman overtook human action within the network of a level 7 nuclear accident.

Chapter 1

The Chernobyl Effect: From Urban Explorer to ANT Detective

1.1 Chernobyl and I

> Good evening, comrades.
>
> As you all know, a misfortune has befallen us - the accident at the Chernobyl nuclear power plant. It has painfully affected Soviet people and caused the anxiety of the international public. For the first time we encountered in reality such a sinister force as nuclear energy that has escaped control...
>
> We evaluate in a fitting manner the objective attitude to the events at the Chernobyl nuclear power station on the part of the International Atomic Energy Agency and its Director General, Hans Blix.
>
> In other words, we highly appreciate the sympathy of all those who treated our trouble and our problem with an open heart.
>
> But it is impossible to leave without attention and political assessment the way the event at Chernobyl was met by the governments, political figures and the mass media in certain NATO countries, especially the U.S.A 'Anti-Soviet Campaign'.
>
> They launched an unrestrained anti-Soviet campaign. It is difficult to imagine what was said and written these days - 'Thousands of casualties', 'mass graves of the dead', 'desolate Kiev', that 'the entire land of the Ukraine has been poisoned', and so on and so forth.
>
> Generally speaking, we faced a veritable mountain of lies - most dishonest and malicious lies. It is unpleasant to recall all this, but it should be done. The international public should know what we had to face. This should be done to find the answer to the question: What, in actual fact, was behind that highly immoral campaign? (Gorbachev, 1986)

The Chernobyl Nuclear Power Station accident of April 26th 1986 saw two massive steam explosions rip apart the core of reactor number 4. These catastrophic blasts turned a huge part of the facility into nothing more than cinder, started several nuclear fires, and spread the reactor's dangerous radioactive innards across the landscapes of Europe, thus forever etching the name of the once-little-known power station in northern Ukraine into the global psyche. It was the type of accident that defied belief and preemptive planning: an uncontrolled release of radioactivity coupled with the total destruction of every innate reactor safety mechanism, resulted in the worst nuclear accident the world had ever witnessed. In 1990, the International Atomic Energy Agency (IAEA) introduced the International Nuclear and Radiological Event Scale (INES), a system that classifies events that occur outside of normal operating practices on a scale of 1 to 7. The IAEA (2008, 10) describes a level 7 incident as one that features a "Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures." Chernobyl was the world's first level 7 accident, and the only other is the 2011 Fukushima Daiichi accident in Japan. The severity, magnitude and geographical implications of the accident are not easily understated. The event of Chernobyl was so disruptive that it arguably created a new paradigm of risk, and produced an unwelcome benchmark that materially depicted the worst nuclear accident imaginable. The stricken reactor paid no attention to international boundaries as it billowed its radioactive innards across huge swathes of the European landscape and, in many places, 30 years later, its toxic legacy continues to impact upon the daily lives of many. This is the material reality of the accident, the byproduct of a malfunction within a nuclear non-human/object situated in a remote part of Ukraine.

Power stations are vast machines, requiring, in some cases, thousands of workers to operate, care for and maintain them. Yet, the general principle through which they actually produce electricity is surprisingly simple. Whether dealing with a gas, coal, oil or nuclear facility, the act of boiling water into steam to spin turbines remains a constant. Thus, regardless of the type of fuel being used, the sole purpose of the beating heart of an electricity generating facility is the creation and sustainment of a heat source. This governing principle may be easy to grasp, but proceedings become much more complicated as soon as the materiality of the object tasked with creating/sustaining said heat source is brought into analytical focus. Akin to washing machines, computers, cars, filing cases, mobile phones and any other series of technological objects, designs of nuclear reactors are numerous. The model of reactor used within the Chernobyl facility was the pride of the Soviet nuclear industry. Officially known as the 'Реактор Большой Мощности Канальный' (Medvedev 1989), or the RBMK, these mammoth non-humans are, even to this day, still some of the most powerful electricity generating machines ever created (Ancius *et al* 2005). A complicated mass of super strength steel, reinforced concrete, graphite and uranium, with a design ethos that allowed for theoretically limitless scalability in terms of megawatt production and, as was painfully highlighted by the accident, the unintentional ability to succumb to terminally critical malfunctions.

Nuclear technology is wildly complex, and the physics that underpin its deployment, exclusionary. For many, due to the towering knowledge barriers of the industry, their opinions of the accident have been co-formed by media and governmental appropriation of it, representations guided by the geopolitical pressure cooker of the Cold War, interested stakeholders, environmentalists, the oil and gas industry, and so on. As can be seen from the above extract, from the former General Secretary of the Communist Party of the Soviet Union, Mikhail Gorbachev, during his first public address after the accident, Chernobyl was a source of pain and suffering for the Soviet Union - a critical malfunction which irreparably dented their technological and engineering pride. Chernobyl is many things to many people and this research project reflects what it has come to mean for me.

The central research question asks how has Chernobyl travelled? There is a very literal answer, in that its radioactive cloud spread radio caesium-137 across the countries of central and northern Europe, and this material traversal is accounted for in one of the empirical chapters below, but this is only part of the answer. The use of the ambiguous verb 'travelled' within the primary research question is tasked with opening up the heterogeneity of the accident; in that there are a multitude of typically unseen trajectories of the event, outwith the spread of radioactive material. Scientific and engineering domains shrouded by disciplinary knowledge barriers and clandestine activities of international agencies/governments have all experienced the travels of RBMK no4. Thus, in order to explore these unsighted, yet, not invisible associations, a theoretical and methodological apparatus capable of accounting for these traversals must be utilised.

The primary theoretical underpinnings of this project are Ulrich Beck's (1992) risk society approach and Ian Shaw's (2012) notion of evental geography; the former has a very real connection to the accident, in that Beck routinely utilises the spectre of Chernobyl as a means of vindicating his concept of manufactured risks, and the latter is a theory of monumental events and the creation of new worlds in their wake. Throughout this thesis, the two theories work in unison, with evental geography providing the means of identifying the new worlds created by the event of the Chernobyl accident, while Beck's approach facilitates the characterisation of these worlds; that is, it renders visible the impacts that the disaster had upon conceptualisation of risk within the nuclear industry and the wider public sphere. The amalgamation of these two analytically bountiful theoretical constructs, and the underlying methodological architecture, shall be covered in detail in Chapter 2. The engine powering this endeavour is Bruno Latour's (1996; 1999; 2005; 2013) Actor-Network theory (ANT), an ontologically insistent methodology that argues for, among other things, agency overtaking action. To answer how the accident travelled, a detailed account must be fashioned of how its agency; that is, the agency of the nuclear non-human, RBMK no4, the central actant of the network, has *engendered action*. Therefore, an account is needed for how this stricken machine in Ukraine sparked new, spontaneous and purposeful human action in the wake of the accident, thus highlighting how its agency has overtaken the resulting human action. Or, in other words, the task is to render visible the travels of this most unique non-human hybrid throughout a host of different domains since the event of 1986. The actions accounted for within this project range from the cauldron of panic during the immediate clean up operation, to the scientific practices of actors tasked with assessing the continued validity of the current gold standard system of radiological protection. As a result of this heterogeneity, a discursive ordering ripples outwardly in space and time from the event of 26th April, 1986. The project hence requires the use of a diverse range of Latourian tools, methods of enquiry provided by Latour to aid an ANT scholar in their quest to 'follow the actors'. The adaptable concepts of mediations, translations, panoramas, networks, associations, actors and actants, are the primary lexicon of the approach, and, once again, the role of each will be detailed during the exploration of this research's theory and methods in Chapter 2.

Prior to the theoretical, methodological and empirical heart of the project, let me account for two more nodes of action produced by RBMK no4; three, if one considers the writing of this chapter. These two instances are my personal excursions to the site of Chernobyl, once as an Urban Explorer, and once as a scholar of nuclear risk, science and technology. For this researcher, Chernobyl has featured prominently during two distinct phases of self-identification. As I was born on the 1st June, 1986, I am a 'Chernobyl baby', and as time marches on we, Chernobyl and I, will always share chronological milestones. This synchronisation is not a governing agency behind my fascination with the facility in the Ukraine; rather it is nothing more than a coincidence. Throughout my younger years I had been made aware of the accident as a result of reading/watching anniversary news pieces recounting aspects of the disaster, and the ever present ban on the sale of livestock/produce from spaces across the UK as a result of RBMK no4's deposition of radionuclides, routinely alerted me to the accident's existence. Its captivatingly mysterious allure only caught my inquisitive nature, however, during the years of my undergraduate degree in Geography at the University of Strathclyde.

At that time, I was fond of 'going places I was not supposed to go'; that is, I was a participating member of the UK's Urban Exploration community – a group of people accounted for by Garrett (2010). Urban explorers are people who transgress the spaces of abandoned buildings, industrial facilities, military complexes, underground tunnel systems, disused hospitals and so on, and photographically document the consequential adventure. Governed by the mantra of 'take only photographs, leave only footprints', these urban ghosts feed upon the forgotten avenues of our urban fabric. Initial fascination mutated into my willing participation, and a byproduct of my new hobby was a unique case study for my undergraduate dissertation - *Take only Photographs, Leave Only Footprints: the reclamation of space by Urban Explorers*. During the empirics of the project, I interviewed Scotland's premier 'Urbexer', and at one point conversation turned to Pripyat, the 'Atomic City' built specifically to house the workforce, and their families, of the Chernobyl Nuclear Power Plant (NPP). This city once housed 50,000 people and was purpose built at the same time as the NPP. It thus led an interconnected existence with the Chernobyl facility, and this Urbexer described the now ghost town as the 'Mecca of Urban Explorers'. At the time the name meant nothing to me, but the promise of an entire city, abandoned for *decades*, was enough to convince me that I had to make the trip.

Upon completion of my undergraduate degree, I used my newly gained research skills to operationalise the logistics of this adventure for myself and the aforementioned Urbexer. Flights booked, permits unscrupulously granted, and a feasible route through the Exclusion Zone, a formally sectioned off area around the power plant and Pripyat, was charted by means of Googlemaps. Even at this point, the accident itself was of little interest to me; rather, it was the agency of Pripyat's rows of high rise flats and community structure that drove my foolhardy actions. My former lecturers and supervisor advised me against the trip, citing radiation as a major concern, yet I paid no attention. I felt that I had done enough research to assert that the higher-than-normal levels of radiation would not kill me during this visit, and, crucially, the illusionary sense of immortality a youthful male can experience is a powerful motivating catalyst. I have managed to get myself into several *difficult* situations over the years, and I have always got myself out of them, so I felt no fear at the chance of staging an excursion into one of the world's most inhospitable spaces – only excitement. Furthermore, the 'prestige' of the exploration within the Urban Exploration community had no bearing on my decision, I just *had* to see the city for myself. Why travel hours within the UK to see single factory, when a supposedly vacant urban landscape lay within reach?

What follows is a brief reminiscence reassembling of my first trip to the Zone, a highlights reel of experiences and memories of Pripyat, that will feed into my most recent excursion back to the Zone. From Urban Explorer to scholar of nuclear risk, science and technology, the Chernobyl Nuclear Power Plant has been the driving agency behind my personal transformation.

1.2 Lost in Translation

Figure 1.1: Warning signs at the entrance to the Exclusion Zone (source: researcher's photograph 2015)

The main entrance to the Zone is an intimidating place. The road is flanked on both sides by old Soviet military buildings and rusting signs warning against trespassing without proper permits (figure 1.1). We were granted access by the Minister of Energy within the Ukrainian government, and one of the only pieces of advice he gave us was not, under any circumstances, take pictures of the checkpoints. Pictures from my first excursion are something of a rarity, due to a chance meeting and unavoidable altercation that rendered the pictorial delineation of the trip 'lost to the Zone'. Thus, it should be noted that every picture presented in this chapter was taken during my most recent trip, as a fully fledged scholar of nuclear risk, science and technology.

The first checkpoint, as with every point of access within the Zone, is relentlessly ordered and overseen by a military sensibility. As I arrived, a tour bus had just been cleared to enter and the guardsman turned to me and impatiently gestured for my permit. Prior to embarking on this trip I had received an email containing a letter in pdf form, written in Ukrainian, by the aforementioned Minister of Energy - the total expenditure required to gain this discursive pass was roughly 80 pounds Sterling. As the sheet of paper left my hand I suddenly realised that I had no idea what the letter said, and the reality of the situation momentarily dawned on me. I was standing at the entrance to one of the world's most inhospitable spaces, with an Urban Explorer I had met only three times previously, and I had just handed over a letter from a governmental official paid through the Eastern European Money Transfer system. I had not even told my parents where I was going as I knew they would have disapproved of my plan. The naivety of my actions and youthful mindset that brought me to this unusual situation troubles me to this day.

The guardsman read the letter with a look on his face that I could not easily gauge. After a few tense minutes he called over to a colleague, a towering man wearing full military attire and carrying a short stock AK-47 (as did all of the checkpoint personnel). They conversed for a moment and then the second man proceeded to use his radio to request the presence of someone else. Stress is a difficult emotion to manage; in an instant it can turn into panic, and if one does scurry down that rabbit hole the resulting actions rarely result in an improved situation from the one that sparked the stress in the first place. You learn a lot about yourself in *truly* stressful situations; I have always attempted to be pragmatic in the pursuit of emotional management. What is the point of panicking? Nothing constructive will ever result from it. Granted this is easier said than done, but as previously mentioned, I had a few years of Urban Exploration experience under my belt, and it is certainly not an activity for the easily frightened.

After a silent and prolonged optical examination by the two guards, a door opened in the larger building on other side of the road, and an older member of the military staff appeared. Due to the ornateness of his attire, and the fact that the other two men had radioed for him to inspect our paperwork, I can only assume that he was an officer. He strode across the road and greeted the two guards with a cheery demeanour. Ukrainian was spoken, the letter inspected, and he turned to me and asked, in surprisingly good English, how we planned on traveling to Pripyat. Relief washed over me in a calming wave. We native English speakers enjoy many benefits; our mother tongue is spoken all over the world, and in most European countries they even provide English signposts, menus and the like. This adventure to Ukraine was my first time in a country that spoke a *totally* different language, and as soon I arrived in Kiev my linguistic ignorance became painfully apparent. The Cyrillic alphabet is as intimidating as it is charming. Typically one can hazard an educated guess at the meaning of a word when in France, or Germany, or any country that uses the Roman Alphabet for that matter, but the Cyrillic alphabet obscures its meaning behind an array of 'symbols'. Upon reflection, my total lack of preparation with regards too the language barrier was a major oversight, and with every passing unsuccessful social exchange my confidence in being able complete this journey wained. So, at this most important juncture, to hear the Queen's English through a thick Eastern European accent was akin to being thrown a life vest in a vortex.

This relief must have been reflected on my face as the officer beamed a smile at me as he repeated his question. I told him that I had charted a route to Pripyat and we were planning on simply walking there and back, a tactic he found incredibly funny. After he translated my answer to his subordinates, they too found it amusing that we planned on attempting to walk the 20 or so KMs to Pripyat. Even to this day, after several more trips to the Zone, I do not see why this was perceived as a joke. Granted the journey was in fact a lot longer than I anticipated, but it could easily be completed in a few hours. Regardless, once the officer had regained control of himself, he motioned over to a car parked outside the building from which he emerged and told us to get in it. I thought nothing of getting in a vehicle with a Ukrainian military official and driving into Chernobyl's Exclusion Zone; in fact I was quite happy as our bags were extremely heavy and the decreased journey time meant we would have longer to explore Pripyat. The car itself was a decrepit Soviet era relic, sporting a manufacture's logo that I have never seen before and its stank of petrol.

Figure 1.2: Road leading away from the main checkpoint of the Zone (source: researcher's own photograph 2015)

The road network of the Zone plunges through the dense forests of the region in arrow straight lines. The site is roughly two hours north of Kiev, and, prior to the power plants' construction, this entire area was sparsely populated, with the traditional Jewish town of Chernobyl being the main population hub (Waskow 1986). The directness of the road network alludes to the history of the space and the isolated positioning of the facility. The roads connect one place to another with minimal deviation from the primary artery.

Figure 1.3: Radiation warning sign at roadside (source: researcher's own photograph 2015)

Yellow and red radiation warning signs pepper the wooded road sidings (figure 1.3), and the occasional abandoned building peers through the foliage. The Zone is split into two regions, the 30km and the 10km, each with its own military check point and dosimeter station - large rows of machines tasked with scanning for radioactive contamination. All that has been accounted for thus far took place at the outskirts of the 30km zone. There is one main road that connects the NPP and the town of Chernobyl with the outside world. This is the road I had planned on travelling, but it was not the one chosen by our military taxi driver chose. After roughly two KMs heading down the main road, he took a left onto a small single track and proceeded to hurtle along it close to the limit of the car's performance. I have always been a fan of speed, it is one of life's most primitive of pleasures, but this vehicle felt dangerous at normal levels and positively suicidal when pushed to its limit. Regardless, I saw no way of asking the driver to slow down without breaking some form of social norm; thus, I quietly gripped the door handle and focused on the thin ribbon of tarmac as it sieved through the trees. When contrasted with my most recent trip; that is, in the format of an official tour, this route seems like an extremely strange decision. However, the entire excursion, from start to finish, was not by the book, so a modicum of poetic licence with the roads travelled is perhaps of little significance, although arguably it coloured my experience and interpretation. The main outcome of this backroad was indeed our lack of exposure to the reality of the Zone. In the years since this adventure I have speculated that this route was a deliberately designed choice to keep us off the main roads, and out of sight from the normal activities of the Zone. If one does not pass through the town of Chernobyl, or near the reactor facility, and instead only spends time in Pripyat, then it is easy to leave thinking of it as a totally desolate place. Nothing could be further from the truth, but I only discovered this years later.

Conversation was at premium during the car journey, and I spent the majority of the time mentally tracking our route in preparation for the return trip. Monotonous perfectly characterises this landscape. The Zone has many spaces: abandoned nurseries, crumbling town halls, historic churches, huge pieces of the nuclear power plant’s infrastructure, and yet on this journey we witnessed none of them. Due to the density and height of the trees, it is near impossible to situate oneself within the landscape, and even the massive Duga 3 radar complex, standing over 150 meters tall is obscured until the very last moment. However, this forestry tunnelling effect produced one of the best surprises of the trip: the moment when we emerged from our wooded enclosure with Pripyat front and centre. Set against blue Ukrainian skies, the crumbling rows of flats and overgrown shrubbery were a beautiful sight for an Urban Explorer.

The journey took 45 minutes to reach Pripyat’s most north easterly point. This is by no means the main entrance, and it appears, in retrospect, to be a back road into the city. At the time I had no idea that Pripyat has a military checkpoint at its primary entrance, and we passed no such regulatory outpost on this journey. This knowledge would have made our exploration even more ‘special’ as it appeared that we had been snuck into the city - a *true* transgression of the space. Regardless, our military taxi driver pulled up at the side of the road, offered us the use of a small hand gun, to which I declined, for him to *insist* that I take his nightstick, before he left us with one piece of advice, “Just remember to stay off the grass”.

1.3 Exploring an atomic city and the demise of the Urban Explorer

Figure 1.4: Satellite view of Pripyat (north west corner) and the Nuclear Power Plant (south east corner) (source: GoogleMaps)

The above image (figure 1.4) delineates the landscape of the 10km inner section of the Zone. The rectangular facility in the south east corner is the nuclear power plant, and the vibrant section of greenery to the north west is the city of Pripyat. The distance between the two is minimal when viewed in this format, and this spatial proximity highlights the symbiotic relationship between the two entities. Today, it is difficult to make out the structures of Pripyat due to the density of the foliage, but one can still make out the slender outlines of the high-rise flats peering out of the trees. The road travelling from the bottom of the image, in a north westerly direction, is the main access point into Pripyat, but, as stated above, my first visit did not use this route. Rather, the two of us were deposited somewhere in the north east of the city, and we journeyed from that point into the heart of the city – the slightly brown area in the centre of the greenery.

I barely knew the Urban Explorer with whom I traveled to the Zone. He is a small and very quiet man, and rarely offered anything in the way of emotive feedback to proceedings. However, as soon as we left the confines of our Soviet taxi he began to bound about like a child at Christmas, and I happily partook in the festivities. Urban Exploration is a form of escapism; for me, it brings back memories of childhood adventures with my friends where we would venture into the fenced facility that houses two huge wind turbines a few miles south of the village where I grew up. These feelings were magnified by the sheer vastness of Pripyat. Nothing can really prepare you for the sight of an urban landscape totally devoid of a human presence and activities. The juxtaposition between its rows of grey, rotting buildings and what one has come to expect from a city is initially very jarring, even for a veteran Urban Explorer. Due to a lack of field notes, and a winding path, I am unable to account for the totality of our excursion through Pripyat. Furthermore, reassembling everything could be perceived, for want of a better term, as rather dull to anyone who is not attuned to the delights of urban abandonment. Thus, a highlights reel shall be provided, and a reassembling of the most immersive *experiences* detailed.

Pripyat is a lonely space, a sad crumbling relic, and the world's premier example of the destructive power of the atom. It is also a seemingly devious space, one that plays tricks on the senses of anyone who explores its deteriorating urban fabric. Buildings creak and moan under the stresses of disrepair, with several suffering catastrophic structural damage over the years.

Figure 1.5: A collapsed School in North West Pripyat (source: researcher's own photograph 2015)

This image (figure 1.5) is of a school situated in the north west of the city that has seen a collapse due to unchecked water damage. During my first exploration I came across this damage as I walked through the green arched door into the classroom on the top floor. It was quite a surprise at the time, but, in hindsight, I should have expected it, as the entire building seemed to shudder under my footsteps as if it was trying to tell me it was dangerous. Upon reflection, it was probably not the safest structure in which to stage an exploration.

The visual aspects of the space are easily represented, but the soundscape is not. If anything, the milieux of strange and, at times, rather unsettling sounds of Pripyat left the largest impression on me. One may think that when humanity evacuates a city it lies silent, and I certainly did prior to inhabiting such a space; however, the reality is very different. Pripyat is a city of large boulevards, all leading to the central square, and monolithic high rise flats line these large streets. The majority of the windows of these structures have been smashed over the decades, and the openings created by the lack of glass allows the wind to funnel through the buildings's carcasses. When there is no 'human-made' noise, the hum of the heterogenous constellations of objects which help comprise the materiality of most cities, nature's orchestra, takes precedence. As the wind increases its bellow, so does the strange whistling noise made by its interaction with the buildings. It dominates the boulevards to the extent that one can focus on nothing else. Furthermore, as there are still so many *things* residing within every structure, the wind perpetually displaces them from their lodgings which results in worrying noises coming from all directions.

Pripyat is a space that demands strong mental fortitude, especially when exploring the site without the comfort and security of a tour or large group. I was acutely aware that we were totally outside of conventional protective systems; my colleague and I were the only people within at least a 3 km radius; neither of our phones had signal, and even if they did, who would we call if we encountered trouble? At the time I found the isolation exhilarating, it felt like I was in truly uncharted territory. Regardless, the constant barrage of unsighted noises coming from the thousands of windows above us routinely challenged my youthful confidence.

The central square was our primary destination; firstly, as some of the most iconic buildings reside there; and secondly, it features heavily in 'All Ghillied Up', a level within *Call of Duty: Modern Warfare*, a popular video game at the time. As we journeyed south towards the square we arrived at the Cultural Palace, a building of great social importance within the city. It is a vast structure, complete with swimming pool, cafes, theatres and gymnasiums. The grandeur of the architecture has stood the test of time and decay. Its clean sweeping lines are supplemented by double height rooms and floor to ceiling windows, now shattered on the floor (figure 1.6).

Figure 1.6: The main hall of the Cultural Palace (Source: researcher's own photograph 2015)

Due to the labyrinthian layout of the building, on several occasions we found ourselves arriving in a pitch black room, when we thought we were heading into the next massive opening. After an hour of guesswork exploration, we eventually arrived at a small door that opened out onto the main gymnasium, a doorway that revealed a view I shall never forget.

Figure 1.7: View from the mezzanine of the gymnasium in the Cultural Palace (Source: researcher's own photograph 2015)

The above image (figure 1.7), taken during my most recent trip to Pripyat, is of this view, and it encapsulates so many aspects of Pripyat. The patchwork of ruined decor, the relentless reclamation of the space by nature, and material snippets of the city's life before April 1986, all contribute towards a distinctive character that I have never experienced again. The yellow and red ferris wheel has become an icon within Chernobyl discourses, notably within video game representations of the space and the countless Urban Explorer accounts of the site, and its colourful presence within a landscape of grey, white and brown is a sight to behold. Due to my Google map pre-planning, I roughly knew the location of the amusement park, but I had made a pleasant miscalculation and was rewarded with this surprise framing of the wheel. My exploration colleague and I must have stood in silence, gazing at this visa for ten minutes before I suggested working our way down to see it close up.

As can be ascertained from figure 1.7, the gymnasium was situated on the first floor of the Cultural Palace, and as we ventured back down into its bowels we came across piles of discarded Soviet propaganda, rooms with plants actively growing on the floor, entire sections of the collapsed celling, and a room filled roughly half a meter high with old books. If one could visit only one place within Pripyat, it should be the Cultural Palace, as it is akin to a microcosm of the entire city. As one would expect from any building left to the wrath of nature, structural rigidity has been replaced by creaking weaknesses. The only instances when I felt sure footed were on the concrete of the streets or solid stone staircases, and the byproduct of the resulting slow pace of exploration was a lengthy journey time. This is a hallmark of the Zone, and one that cannot be gauged or experienced without actually inhabiting the space. Every activity takes much longer than initially anticipated: whether simply traveling from point A to B or actively exploring a building, the pre-planned designated time allowance is never enough. Urban Explorers are well trained in slowly working through an abandoned building, but when the number of available sites is increased to the levels present within Pripyat, time seems to pass at an accelerated rate. Thus, it took roughly a hour to travel from the gymnasium to one of our chosen landmarks, prior to reaching the amusement park; that is, to the swimming pool - a journey which should take no more than 5 minutes. Once one of the city's premier attractions, the 50 meter pool now lies filthy and broken (figure 1.8). We did not spend long in this room as the allure of the amusement park was pushing us forward. After a purposeful retracing of our steps we excited the Cultural Palace and headed directly towards the yellow and red ferris wheel.

Figure 1.8: The swimming pool of the Cultural Palace (source: researcher's own photograph 2015)

Figure 1.9: The amusement park (source: researcher's own photograph 2015)

The wheel is accompanied by three other fair ground rides, but they are so rusted that one can barely make them out against the dense trees (figure 1.9). As it was set officially to open on May Day of 1986, this rare feature of Soviet urban landscapes was never used as the population of Pripyat had been evacuated almost immediately after the accident. The frame of the wheel sways in the wind, and the carriages seem to be in perpetual motion caused by their entanglement with the surrounding trees. Due to its ‘popularity’ among those who have ventured into Pripyat, it seems almost cliched to state that this eerie and ultimately depressing space was the main highlight of my first trip.

The remainder of our first day was filled with more mundane urban exploration activities, journeys through the less interesting buildings such as flats, cafes and hotels. It was brought to an abrupt end by an altercation close to the block of flats where we had chosen to sleep – a chance meeting that soured the rest of the journey. Tired and weary from our busy day exploring, my Urbex partner and I returned to our designated sleeping spot, but just as we turned a corner towards the entrance, we were met by four men seemingly waiting for us. Due to their lack of military attire and menacing demeanour, I knew their intentions were unsavoury. I am a son of Glasgow, and have encountered situations of this nature over the years (obviously not staged within the emptiness of a Ukrainian ghost town). When outnumbered and approached by seemingly confrontational assailants, I knew from experience that physical hesitation only empowers the other party; thus in this instance, my autopilot took over and I grabbed my Urbex partner by the jacket and strode towards the four men. They looked weak, tired, and desperate, anything but physically intimidating, but when those agencies are combined the end result is the unpredictability of action.

I am not sure how they thought this encounter would play out, but I doubt they expected staunch Glaswegian resistance in the face of their superior numbers. The smallest member of the group appeared to be their spokesman and he barked Ukrainian at the two of us in an impatient tone, motioning towards my Urbex partner’s very expensive camera with a rather pathetic looking kitchen knife in his hand. As I stated above, my exploration partner is a small, quiet man, perfect for covertly infiltrating abandoned buildings, but ineffective in a charged situation of this nature. Against my instructions he readily handed over his camera, then his wallet, phone and passport – I do not hold this against him, he was terrified and seemingly wanted this ordeal to conclude as quickly as possible. With an unprecedented bounty in hand, the group’s ringleader turned to me and barked further orders, no doubt believing that he would achieve the same result. For numerous reasons, most notably my pride, I was not ready to hand over my essentials, especially in this most remote of locales. Instead, I took the nightstick our military taxi driver insisted I take from my belt, pointed it at every member of the group, and informed them to remove themselves from this situation. Well, words to that effect. Obviously, the language barrier rendered my warning as futile, and the ringleader moved a few steps closer notably bolstered by his previous 'victory'. I am not a violent man, but in this situation I saw no other option and as he approached I used the nightstick as it was designed. The small provocateur crumpled on the ground, and, for what seemed like an eternity, I stared off with the remainder of the group in silence. Eventually, with their ringleader incapacitated, they started to retreat, dragging their fallen comrade away to a small car parked on the other side of the opening.

My partner and I quickly entered the block of flats where we chose to sleep in as soon as the group reached their vehicle. In hindsight, we should not have gone straight to our home base, and as a result, my first night in Pripyat was spend awake with my back pressed against the flat's door as my Urbex colleague slept. After the adrenaline had faded the reality of what had transpired dawned on me, the worry set in. Our second day featured none of the joyous discoveries of the first, and instead the majority of it was spent wandering back to the main checkpoint of the 30 km zone. Instances of this nature are never welcome, but I was content as we had encountered all that the Mecca of Urban Explorers had to offer, both good and bad, and I left feeling extremely relieved but fulfilled. We shall return to the city of Pripyat in Chapter 4.

1.4 A paradigm shift: from explorer to detective and the toolset of discovery

Figure 1.10: View from Pripyat high-rise flat (source: researcher's own photograph 2015)

Shortly after returning from Ukraine, I submitted a PhD proposal that sought to further my research into the UK's Urban Exploration community. It was unsuccessful. Obviously this was disappointing, but in the same breath I was perhaps relieved. After the trip I had lost interest in the activity, as it felt like I had accomplished everything I could as an Urban Explorer; and so I began to think about other aspects of the accident, most notably, what actually happened to create the space of Pripyat. This shift in personal interest began on a rooftop in the southern quarter of Pripyat. The above image (figure 1.10) reassembles the vista that I witnessed prior to returning to the main checkpoint of the zone. In the summer months, Pripyat is more forest than city, and thus the rooftops of the high-rise flats are the best way to appreciate the scope of the city's urban landscape. As I stood gazing at the view, my attention was drawn to the mammoth complex on the horizon, the hulking mass of steel and concrete almost dead centre of figure 1.10. I knew what it was, yet I was surprised that I knew very little about it. I felt a little ashamed that I had travelled to a distant corner of Europe to see nothing other than a ruined city, but not the cause of its desolation. Pripyat is a form of 'disaster pornography', the epitome of the 'disaster tourism' industry (Shondell Miller 2008; Kelman & Dodds 2009), a window into a *real* post-apocalyptic landscape and the material end product of Beck's "manufactured risks" (1992). Focusing solely on the city is akin to a detective fixating upon the victim of a crime, when the real task at hand is seeking to understand the perpetrator.

This inceptive interest in the material cause of the accident; that is, the creator of Pripyat's current condition, turned into fully-fledged obsession and I subsequently began to investigate the accident of 1986. This groundwork was conducted during my Masters degree, and towards the end of this year I submitted a second PhD proposal that sought funding to research the accident. This proposal was successful, and, as I stood at the outset of the largest project that I have ever undertaken, the necessity of a robust methodology presented itself. Phenomena akin to the Chernobyl disaster are innately heterogenous due to their evental nature, potent agency and the diversity of the actions engendered. Furthermore, recalling the Gorbachov speech at the outset of this chapter, it can be inferred how this material malfunction in a remote site in Ukraine has been internationally appropriated. He speaks of "*a veritable mountain of lies*" or, in other words, a raft of (mis)representations that, in his eyes, have unfaithfully accounted for the accident and its material byproducts.

These mediations represent an 'end product', the final form of discursive delineations of the materiality of the accident, and their creation is imbued with the agencies of interested stakeholders. In other words, representations of this kind are the epitome of a Latourian 'panorama' (Latour, 2005), a purposefully slender window that seeks to cast a happening in a specific manner. Such representations did not satisfy my interest, predominantly as I hoped to discover unmediated — or less mediated — accounts of the accident, ones provided by human actors present at the event and centrally involved in its unfolding, as well as ones provided by the likes of engineers and scientists for whom, ideally at least, the 'maths' of the nuclear non-human should be *translated* not mediated. I also wanted to account for the lessons supposedly learnt by the nuclear industry, to learn of the *actual* risks associated with this Soviet type of reactor, and to ascertain the dangers really associated with the spread of radiation from the belly of RBMK no4. Moreover, I needed to understand how the accident was mitigated, both in the Ukraine and internationally. Thus, I required a methodology that enabled me to situate my analysis, as far as possible, within the material realm of objects/devices/hybrids and their documentation, for only then could I produce an account that spoke to the complexities of the situation, facilitating a charting of how the accident 'travelled' through these areas of enquiry. The shape of my conceptual and methodological apparatus shall be provided in the following chapter, and the purpose of this subsection here is to twin the practical methodological underpinnings with material sites at the Chernobyl facility. In effect, I am purposefully situating the analysis within the material realm, and highlighting how my methodology traced outwardly from its constituent objects and spaces.

As stated above, Actor-Network Theory (ANT) provided the conceptual and methodological toolbox for this endeavour, and, akin to a detective looking to solve a crime, the approach necessitates the discovering of material evidence to support any claim made (Latour 1996, 1999, 2005). Thus, the first empirical chapter of this project (chapter 3) accounts for the scene of the 'crime', or, rather, the epicentre of the event: that is, RBMK no4 of the V.I Lenin Nuclear Power Station. This massive object is the central actant of the network in question, and discovering how it has travelled necessitates, to begin, an account of its ontology. This is a challenging task as a nuclear reactor is an unapologetically complex object, one that demands certain levels of nuclear engineering and scientific knowledge to understand its form, and so sustained reading of academic journals and reports of the International Atomic Energy Agency (IAEA) was conducted. Sources of this nature form the empirical backbone of this research project. ANT, among other things, has "developed a science studies that entirely bypasses the question of 'social construction' and the 'realist/relativist debate'" (Latour, 1996, 22), in that it affords social scientists a means of accounting for the material practices of the 'hard sciences' without seeking to *explain* them by means of social theory. Or, in other words, it potentially sidelines the addition of epistemological elaborative layers. Thus, when detailing the discursive outputs of nuclear scientists and engineers, related to the RBMK design of nuclear reactor, the role of social-science explanatory agent is vacated, or at least radically reconfigured, and the task of tracing the material pathways of the actant through its network is arguably centralised. In terms of operationalised methods, Latour's *Science in Action* (1987) provided a means of identifying the battleground within and tracing connections through the pages of said journals and reports. This orientation required accounting for the creation of the 'black box' that explained how the accident manifested itself within RBMK no4, and necessitated a process that 'rendered visible' the actant, namely the object of the reactor itself. This task was made easier by the immutable nature of its ontology; that is, the finalised form of the of reactor - there can be no polemical discussion about the structure of an object when its discursive blueprint has been translated into material existence.

Today, when seeking to account for an academic network, Google Scholar's 'cited' function represents an ideal window into its nature, structure and key actors. It provides a means of rendering visible the connections between articles and their authors - be it negatively or positively. Several key phrases were used as the starting point of enquiry: 'RBMK design', 'inefficiencies of the RBMK', and 'causes of RBMK malfunctions' were the three primary searches. Note that the word 'Chernobyl' was not used, but rather the official name of the reactor. The reasoning here was to test the agency of RBMK 4 within this academic domain; in essence, inceptively to discover how influential the explosion had become within the areas of academic enquiry tasked with researching the accident. Every article discovered by these searches referenced RBMK no4 and the Chernobyl facility, and subsequently it appears that an entire trans-disciplinary sub-field has been created by the nuclear non-human in Ukraine. To an extent, this literature - spanning academic, technical and political texts - becomes a material object for my project: in that I chart my moves through it, my 'following' the network, in a manner analogous to how I track the motoring, breaking and travelling of RBMK no4 as a material thing (dispersing into countless smaller material 'things'). The steadfast and extensive use of the ANT's lexicon throughout this research should be viewed as the researcher's attempt at being rigorously Latourian, even, occasionally, at the expense of discursive clarity. Again, to underline, Chapter 2 addresses the utilised conceptualisations and methodology — it represents the terminology 'roadmap', one that details why these terms are being used, and the analytical purchase they pertaining too.

My most recent trip to the Zone featured none of the isolation and danger of the first. Rather, due to University risk assessment protocols, and a much more mature mindset, I returned with the aid of the Solo East Tours company. This tour company is the oldest, most reputable in the Chernobyl tour industry, and it is the one of choice for news agencies, television shows (Top Gear used them to film in the Zone) and international agencies. Due to their experience, every aspect of the trip is professionally catered for, and the safety of customers is of paramount importance. The concept of radiation, the invisible and sometimes dangerous entity, sparks fear in most, and rightly so in many cases, but as shall be highlighted in later chapters (chapters 5 and 6), low-doses are rarely damaging, especially when a person is subjected to them for a very brief time. One must remember that the Chernobyl facility was in operation until 2000, with units 1, 2 and 3 remaining relatively undamaged by the accident. Thus, for 14 years, thousands of people lived and worked in the Zone every day. Even today, approximately 3000 people work within the confines of Zone (Rothbart 2012). The only way that this influx of people could be sustained is through a comprehensive clean up operation, which was achieved in a matter of months by the Soviet Union. The main network of the Zone features lower levels of radiation than Kiev (and most cities in Europe), and even the reactor facility itself has only slightly higher than normal levels. During the journey to the Zone's entrance, the tour company showed several films on the bus, one of which accounted for an interesting experiment. One of their employees was travelling to America by plane, and had a geiger counter with them. Throughout the flight this person took periodic measurements, revealing that the levels experienced during this normal transatlantic flight were significantly higher than any ambient doses that a visitor encountered during their time in the Zone. Thus, it appears that situational context, when fused with scientific rationale, casts aside perceived/imagined risks, and renders visible the reality of a situation.

Figure 1.11: The Golden Corridor (source: researcher's own photograph 2015)

During my most recent excursion to the Zone, I was lucky enough to gain access to the reactor facility itself. This rectangular building houses units 1, 2, 3 and the doomed number 4 in a linear pattern. Figure 1.11 is of the 'golden corridor', a passage that runs through the entire facility and at the far end of this picture is the makeshift wall that was built to close off the ruined unit 4. Therefore, roughly 100 meters away from where this picture was taken lies the object of the reactor, including the ruined control room where the sequence of events that produced the explosion took place. It is a sobering experience to traverse the space, especially after consuming a huge amount of information detailing the days, months and years preceding and succeeding the accident. The aforementioned documents elaborating upon the reactor type, and the material pathways to the accident, speak in purposeful efficiency and scientific terminology: "Zirconium alloy E635 as a material for fuel rod cladding" (Nikulina *et al* 1996); "computer code RELAP5 validation with RBMK-related separate phenomena data" (Urbonas *et al* 2003); "evaluation of the activity of irradiated graphite" (Plukiene *et al* 2005). These are just a small sample highlighting the nature of the works conducted upon these machines; that is, the intense materiality of the nuclear non-human and its ontological characteristics.

Addressing discourses of this nature allows one to gain a fuller understanding of the object, and consequently facilitate a mapping of its network, although they can cloud one's perception. The role of a social scientist within a scientific network is not one of practical participation, but rather our duty is found within synthesis: synthesis of the heterogenous range of scientific actions being performed and meta-evaluation of the process. Once again, akin to a detective standing at the scene of a crime that she does not fully understand, our role is to piece together the disparate puzzle, thus reassembling component parts that obscure their connections. A means of keeping oneself 'on track', and focused upon the material phenomena in question, is to experience it first hand. I certainly found this 'ontological witnessing' very helpful when seeking to keep RBMK no4 firmly within my analytical crosshairs.

The first empirical chapter (chapter 3) resists the temptation to provide a detailed account of the constellation of human actors that conducted research work upon the RBMK fleet. Granted, their research forms the backbone of the chapter, but the nuclear non-human of RBMK no4 is the centre of the network and the project - it is the most important actant. Human actors play a central role within the remaining empirical chapters, but their actions are a product of the ruined reactor's new agency, and the way they act are material example of how the non-human has travelled. Thus, the first chapter is tasked with taking seriously the role of the *object*, its materiality and its breaking, and affording it a space of its own without infringement by human actors.

The second empirical chapter (chapter 4) accounts for the hours, days, weeks and months after the accident, and the heroic actions of the liquidators, firemen, pilots, construction workers and military personnel asked to tame a nuclear inferno, the likes of which the world had never witnessed before. It is an anatomy of the *event*, in its chronological immediacy to the explosion. This chronological movement is coupled with a spatial shift outwardly from the reactor site, albeit one that does not leave the 10km exclusion zone. It is at this point that human actors take a more central role, and the first-hand accounts of the facility's key staff members can be analysed. Actor led contextualisations of this period are rare, with only a few 'unmediated' iterations existing. Dozens of books detail the plight from afar, and such texts have been utilised, but the first-hand accounts of both former Chief Engineer of Unit 1, Grigor Medvedev (1991), and Deputy Chief Engineer Nikolai Karpan (1986) provide the most vivid account of the immediate aftermath, and also too of the bureaucratic struggle to mitigate the event and the new world that it had created. The lack of detailed first hand accounts is an empirical issue, one that cannot be overcome. Thus, the above mentioned accounts feature prominently throughout this thesis due to them being the only available.

Figure 1.12: Pripyat City Sign (source: researcher's own photograph 2015)

The Soviet reluctance to admit that something had happened is well documented, and the latency of the Gorbachov address at the outset of this chapter provides evidence of the well-practiced Soviet propaganda machine (the speech took place on the 14th May, over two weeks after the accident). This innate secrecy has resulted in varying levels of dissemination of information regarding the initial mitigation period. Glasnost, Gorbachov's programme to promote a more informatively open political system, was a positive movement for the Soviet government, but the Chernobyl accident highlighted the hollowness of the sentiment. Regardless, enough information exists to reassemble several nodes of action during this evental period. The aforementioned first-hand accounts were cross-referenced by means of secondary information from reputable texts, written by credible actors, in a bid to guard against inaccuracies within the account. This was a challenging task as there is no consolidated discourse detailing this period, each individual text providing instead a patchwork of information, although the accounts of these two important actors helped to unify the discontinuities.

As the accident rippled outwardly from the reactor facility, Pripyat, the power plant's symbiotic Atomic City, was forced to take on a new form, a new role, one outwith its inceptive design. With its human inhabitants swiftly evacuated, the urban landscape of the atomic city was transformed into the site of intense military and airforce activity, a hub of panicked action engendered by the new agency of RBMK no4. During my most recent trip to the Zone, I did not see it as a space that once housed 50,000 people, but rather the launch pad of the helicopter sorties tasked with suffocating the nuclear fire, or the place where the firemen were initially treated after they fruitlessly fought the fire from the roof of the reactor hall. The city is littered with remnants of this epoch, telling of the struggles of the actors drawn to the nuclear non-human. These objects provide a trail of evidence that helps to reassemble the first two weeks of the clean-up operation, thus awarding an ontology to the above-mentioned first-hand accounts. These diverse 'things' range from large pieces of military infrastructure left abandoned in the haste of completion, to the small and personal affects of the people who, in reality, gave their lives to mitigate the accident.

Figure 1.13 shows a firefighter's balaclava in Hospital no 2, in the southern point of the city, an innocuous rag on a table by the main door that emits 107.9 mSv of radiation, a dose several thousand times higher than normal levels. As an aside, later in this thesis, I will explain and debate in detail how radiation is measured, its effects on biological organisms, and account for the international radiological protection systems. During this trip I was informed by the tour guide, the owner of the hand in figure 1.13, that the first firefighters on the scene were taken to this hospital as it was the geographically closest to the reactor, and that their clothing had been stored in the basement. However, a hospital staff member had foolishly taken a large percentage of the clothing from the basement for washing, and subsequently strewn them around the hospital in a panic. As a result, certain areas of the space are indeed now not advisable to be explored.

Figure 1.13: Fireman’s Balaclava in the entrance of Hospital 2 (source: researcher’s own photograph 2015)

The primary driving agency behind Chernobyl’s international infamy was the material spread of RBMK no4’s radioactive innards - the most literal dimension to how the accident traveled. At this point, chapter 5, the empirics of the thesis take another spatial step away from the site in Ukraine and chart a course over central and western Europe. In order to understand this movement, and the entity of radiation, a sustained account of both the atmosphere and ionising radiation had to be produced. Risk is a central analytical theme within this endeavour, and the primary means of assessing the risks associated with Chernobyl’s radioactive dispersion — that is, accounting for its unmediated materiality — is to synthesis the works of the sciences charged with researching the physical entity. Furthermore, in order to assess the risks, those insinuated within both ‘popular discourses’ and academic research, an exploration of how ionising radiation interacts with biological organisms was conducted. These fields are a relative unknown to a social scientist; so, in order to construct a knowledge base, a purposeful ‘scaling up’ of material was performed. This process started with undergraduate textbooks on the subjects, and consequently moved to more advanced material when a competent level of understanding was achieved.

Once this knowledge base was established, and the account moved on to Chernobyl-specific material, a similar methodological system to the one featured in chapter 2 deployed. The Google Scholar search, 'Chernobyl's radioactive dispersion', unearthed a vast network of thousands of texts - once again, the reactor's agency has produced a huge sub-field of study for a variety of scientific fields from biology, to environmental radiation to policy-relevant studies. The reasoning behind the use of the word 'Chernobyl' was purely provided since 'radioactive dispersion' was too ambiguous as it could pertain to Three Mile Island, Sellafield, and the recent Fukushima accident - the three worst nuclear accidents outside of the Chernobyl accident. The radioactive cloud featured a variety of fission radionuclides, but caesium-137 was found to be the material 'breadcrumb trail' that most researchers sought to follow. Thus, these invisible shards of material from RBMK no4 have dispersed this nuclear non-human's agency as they traversed Europe, shaping human action in their wake.

The European Commission's (1998) *Atlas of Caesium Disposition on Europe after the Chernobyl Accident* was utilised in conjunction with the above-mentioned texts. Significantly for this thesis, it also represents the collaborative work of a diverse network of academics throughout Europe, and one of these actors was interviewed about his participation. Ethical approval was sought for the interview with Professor David Sanderson, of the Scottish Universities Environmental Research Centre. Taken on the surface, without said actor's contextualisation, *The Atlas* represents a comprehensive account, country by country, of the spatial dispersion of the radionuclides; but with Sanderson's help, I could identify the nature of its representations, gaps in the methods and the unusual cases of absence. Thus, the combination of all these elements, especially the situated knowledge of an influential environmental physicist, allows this account to probe the 'unmediated' materiality of the situation: that is, to render visible the *actual* risks at play without deformation.

Once again, I can return to the Zone for alignment. The below image (figure 1.14) is of a 'hotspot' close to the cooling tower of the never finished unit 5. The reading of 117.5 mSv is higher than the firefighter's balaclava, yet, without the geiger counter, one would have no idea that this particular spot is dangerous. As an aside, it should be noted that prior to embarking on this tour orientated excursion to the Zone, risk assessment approval was gained from the School of Geographical and Earth Sciences's Risk officer. Granted this 'hotspot' features several times the normative level of radiation, but the tour guide only kept the group in this location for a matter of minutes before moving on. Furthermore, as shall be highlighted in Chapters 4 and 5, even high levels of radiation only become 'dangerous' with prolonged physical exposure. The figure spotlights the obvious, yet easily forgotten aspect of environmental radioactivity; namely, humans' inability to account for its presence. Environmental radiation, much like nuclear reactors, demands scientific knowledge in order to account for its presence and innate risks. The output of the relevant scientific actors and their machines is dense and filled with discipline-specific terminology that is beyond most of the general public. That is, people lacking situated knowledge of the science of radiation rely on mediations of these findings/measurements to gain an understanding of the situation faced. This is not the place to explore the deviations between said findings and their representative appropriations. Rather, the point is to highlight an empirical necessity of social scientists working within technical fields. The only way to account for scientific outputs, in an unmediated manner, is to learn how to consume them and to train oneself within their lexicon. This is not an easy task, but, if the intrepid detective is to compile an airtight case, they must encroach into areas outside of their comfort zone. The end product, outwith the account itself, is a new ability to work within the realm of these scientists, converse with them and, in the process, follow them as they move within their network of professional residence.

Figure 1.14: Geiger counter depicting the levels of radiation present within a 'hotspot' at the makeshift entrance to the never-finished cooling tower of unit 5 (source: researcher's own photograph 2015)

The final empirical chapter, chapter 6, accounts for the actions RBMK no4 has since engendered within international institutions, agencies and organisations. The International Atomic Energy Agency (IAEA) and the United Nations (UN) are the two of great relevance here. One of the major byproducts of the new world created by the nuclear non-human was a recalibration of risk; closely associated with the validity of the Linear No-Threshold (LNT) model of radiological protection. Interestingly, this phenomena featured contradicting directions within the construction of risks, one representing an increase within proactive measures to mitigate the machine's risks, and the other featuring a sustained academic battleground that sought to *decrease* the risk (taken to be) associated with low level radiation. This empirical chapter marks the end of RBMK no4's journey within these domains of enquiry, and the analysis jumps forward chronologically and spatiality. The purpose of accounting for this phenomena last is due to the agency, and potential action of the institutions involved. Both the UN and the IAEA are hugely influential entities, and the actions, reports and recommendations which they made as a result of RBMK no4's agency have had the longest-lasting impacts upon both the nuclear industry and radiological protection sciences.

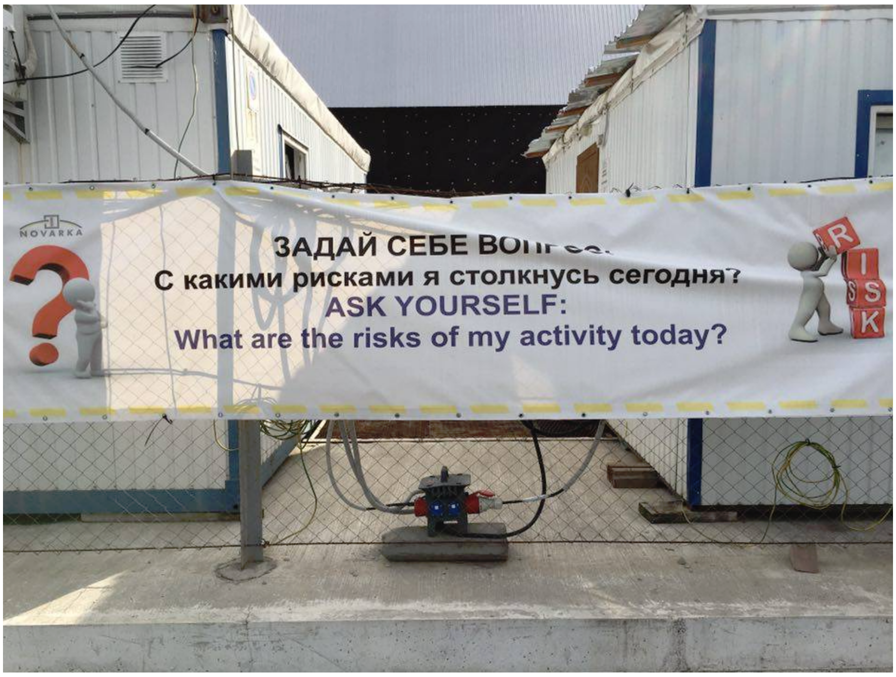

Figure 1.15: Sign pertaining to employee risk at the construction site of the new containment structure (source: researcher's own photograph 2015)

This final substantive chapter features another academic battleground, and, once again, the same Latourian methodological apparatus was deployed. 'LNT debate' and 'Linear No-Threshold validity' were the key word searches, and only articles that directly referenced

Chernobyl or RBMK no4 were used. This is a huge arena of enquiry, with two sides vividly arguing for the pros and cons of the model. The reasoning behind the inclusion here of this relatively unknown polemic is down to the role that RBMK no4 played within its inception. Prior to the accident, there had not been any reason to deploy LNT on a large scale, and thus its hypothesis was untested. Due to the large release of low-level radiation across Europe following the Chernobyl accident, some members of the scientific community began to question the assumptions of LNT, and thus the debate began.

This final chapter marks the point where hugely influential actors and stakeholders enter RBMK no4's network, their interests becoming inextricably infused with the event. The IAEA and UN are regarded as the international gatekeepers of humanitarian protective standards, with the former focusing upon nuclear technologies and the latter catering for the entire spectrum of human 'rights'. Due to the restrictive nature of the UN and IAEA's publications, it is difficult to access any of their 'workings' as only their finalised reports are available, and so, there comes a moment where even the most inquisitive detective reaches the limits of available evidence. Regardless, shying away from these under-researched, and hugely important aspects of the Chernobyl accident runs the risk of producing an asymmetrical account. The methods remain unchanged, but their effectiveness is eroded by institutional firewalls.

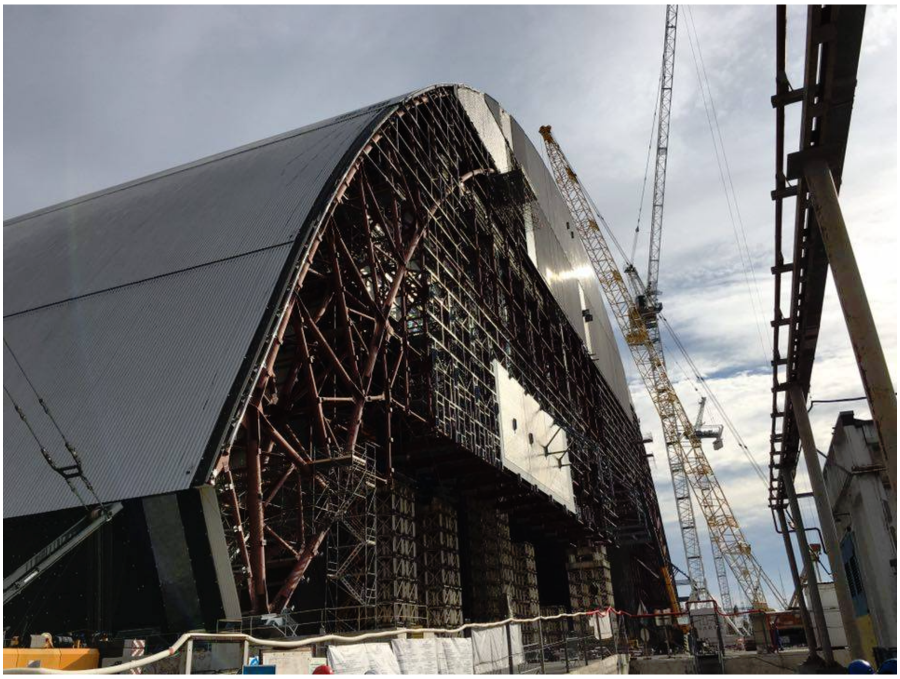

Figure 1.16: West side of the new containment structure (source: researcher's own photograph 2015)

1.5 Concluding remarks

This introduction has attempted to set the scene, create an initial window into the site of the Zone of Alienation – one which draws upon my first experiences of the space. At this time, some 10 years ago, to me, it was a place of wonder and excitement, a site of mystique and the place I felt I had to go for the sake of my Urban Exploration background. Over the course of this research, the site and my own perception of it has changed. The empirical chapters chart the site's journey, how its materially spread across the landscapes of Europe, but also philosophically, with its agency engendering action within countless collectives around the world. Outside of the photographs, my most recent trip to the Zone has been purposefully omitted from this introduction. I felt it was important to depart from my initial understanding of the site and the accident, as this thesis represents not only the travels of RBMK no4, but also my evolving interests as an ANT scholar. During this latest excursion I spent my time accounting for the intricacies of the site, learning of its daily routines and evaluating how it has progressed since April 1986. In effect, attempting to reassembling its network and understand how the materiality of the site has been augmented to contain one of the worst nuclear accidents the world has witnessed. This foundational question is manifested within all of the empirical chapters described above. From the evaluation of the object of RBMK no4 itself, to the creation of the sarcophagus (the original steel shelter of RBMK no4), to the sustained account of how the atmosphere transported radionuclides around the world, each empirical chapter seeks to understand how the site has travelled and evolved over the last 3 decades.

This change in personal analytical obsession was caused by the nature and overall direction of the empirics of this piece of work – the decision I made at the outset of this journey. The insistence of attempting to situate this work within the realms of nuclear science and engineering subversively influenced me (in conjunction with an ANT mindset), as a researcher, to account for an ever moving target, one which was once shrouded in secrecy, subterfuge and myth, but is now, by means of my adopted ANT methodology, rendered visible in sharp scientific clarity.

The concluding passage of this introduction reflects upon the totality of the material and my attempt to synthesise it into a meaningful insight into the accident. This research involves the location and interrogation of a 'travelling archive': a diverse and comprehensive collection of documents that span the last 3 decades. One that has been identified, constructed and explored as a means of understanding the Chernobyl accident. In other words, this involved a huge systematic literature review of several complex domains of scientific and engineering study. Due to RBMK no4's unprecedented ability to 'surprise', destroy and contaminate, it has engendered countless nodes of evaluative scientific and engineering action. The study of 'Chernobyl' has almost become a discipline in itself. Consequently, there is no shortage of material, but deciphering it from a social science perspective was a challenge. The identification of the leading experts within each field was the inceptive mission, and this was achieved by a tracing of the most influential articles within the areas I sought to explore, and identifying the leading members of international programs tasked with evaluating the accident. From there, the entire bibliographies of said actors were read, and reference mined. This in turn lead to the identification of more influential scientific actors, and another abundance of articles. This process was repeated dozens of times.

Over the course of this research I came in contact with several experts within the fields of research applicable to the Chernobyl accident. The knowledge gained through the exploration of my travelling archive allowed me to converse with these actors, using the lexicons of their areas of study. My knowledge of these areas is the product of my systematic literature review process, and I was only able to communicate with these actors in an informed manner due to the strengths and thoroughness of my date gathering methods.

With the passing of the event's thirtieth anniversary, RBMK no4 is still being readied for its final entombment. The above image (figure 1.16) is of the new shelter structure, the largest moving object on earth. The original sarcophagus, the hastily erected steel shelter, was only designed to last for 5 years, yet it has stood for 30. The new containment structure, the result of an international consortium, marks the end of the event itself, the point when the next two hundred years are catered for and the material source of the accident mitigated for several lifetimes. It symbolises a 'putting the genie back in the bottle', returning RBMK no4 not to what it was originally, but rather a spatially sealed-off entity, a dot on a map, a cap-stone on the event (and indeed this thesis). Of course, much that has traveled outwardly from RBMK no4 and the site can never been recalled, but this new aluminium and concrete sarcophagus represents the closing act of the Chernobyl saga, the pragmatic means of finalising the worst accident imaginable.

The simple fact that it has taken 30 years to get to this point of entombment highlights the severity of the event, and the difficulties, both engineering and bureaucratically, that had to be overcome. Nuclear technology has numerous advantages in an era of increased atmospheric carbon deposition, but Chernobyl will always stand as a chilling reminder of its unparalleled disruptive potential. It is fitting summation to end the account at the feet of the new shelter, as it provides a means of looking forwards with the lessons learned fresh in the mind.

Figure 1.17: As close as one can get to the external wall of RBMK no4 (source: researcher's own photograph 2015).

Chapter 2

An ontology of risk in the wake of Geoevent: the conceptual and methodological coordinates

The central research question of this project asks how the Chernobyl accident has traveled (that is, to account for its trajectories through a host of different domains of reality, and this goal will be achieved by means of an Actor-Network Theory (ANT) methodological toolset). ANT was chosen as it facilitates the production of a distinctive ontological description, unabashedly anchoring the analysis within the material realm, in all its intricacies. Specifically, for this project the 'material' equates with the nuts and bolts of machines, the flesh and blood of living beings, and even the paper and pages of documents. However, the method, by design, cannot provide *explanations*. For Latourians convinced by the claims of Latour to be examined below, creating a full description is analytically sufficient, but this supposition is not universally shared. Thus, conceptual augmentation must be applied to the ANT methodological framework, incorporating theories and concepts capable of capturing still more fully the material extent of RBMK no4's agency and network.

This chapter represents the inner workings of this research project, the engine that powers the vehicle. As such, it details Beck's risk society approach as an adjustment to the Latourian intellectual project, subsequently exploring the relationship between Latour's methodological apparatus and the concepts of sites, worlds and risk. Thus, this chapter merges the research's literature review and methodological sections. Commonly, the two are dealt with separately, but, as a result of the 'packaged' nature of the central theory, Latour's ANT, conceptual and methodological interests form a mutually reinforcing whole. Varied in application and diverse in theoretical contributions, ANT provides a researcher with a comprehensive toolset for any analytical endeavour, and its tenets shall be covered in due course.

The purpose of the chapter is hence to explore the governing principles of this research project; that is, to render visible the conceptual and methodological tools required to explore the Chernobyl accident, and to indicate the areas of academic enquiry to which it seeks to speak. This mélange of ideas, concepts and methods has produced an arguably unique outlook, and led to unusual areas of investigation for a social scientist outside of certain specialised fields (such as science and technology studies (STS)). Accounts of nuclear reactors, ionising radiation, environmental physics and radiological protection systems form the empirical core of this research: complex, conflated and expansive hybrid objects/entities, imbued with controversies over their nature, ferocity and risk. The concept of risk features prominently, due to the impacts of the Chernobyl accident upon risk's discourses and articulations. In order to account for this connection, and all of the above phenomena, a researcher must prioritise the ontological above all, believe that 'we have never been modern' (Latour 1993), understand the inner workings of scientific controversies, embrace network thinking, and evaluate the Beckian risk society.

Latour's *We Have Never Been Modern* (1993) is my starting point. It features the building blocks of ANT, and renders visible the connections between Latour's philosophical negotiations and hallmark Latourian methodological tools. The move into the methodological discussion borrows from two further Latourian texts, namely *Science in Action* (1987) and *Reassembling the Social: An introduction to Actor-Network Theory* (2005). Works offering detailed summations of how to analyse the discourses of the hard sciences - as well as showing and how to utilise ANT; that is, how to become an ANT scholar. The discussion here also features extracts from Latour's latest work, *An Inquiry into Modes of Existence: An Anthropology of the Moderns* (2013), as a means of providing linkages between my appropriation of ANT and the most up-to-date version of the approach.

The next key text for me is Beck's *Risk Society: Towards a New Modernity* (1992), an influential book delineating his sociological approach for the evaluation of the concept of risk. The Chernobyl accident features prominently within Beck's book, being used to vindicate aspects of his arguments. Beck's work is rooted within social science analysis, but, it arguably lacks scientific credibility, as will be recounted later. Thus, through the use of an ANT analysis, the secondary objective of this research is to provide an ontology to Beck's risk society formulation, with specific regards to the nuclear industry; that is, to attempt to connect Beck's epistemological master narratives to the ontological works of the hard sciences. For this reason, at various points in what follows, I will deploy the slightly odd-sounding term 'quasi-scientific' to capture my own preferred position; that is, as a critical social scientist attempting to take seriously the ontological discoveries by the engineers/scientists of nuclear worlds. A traditional social science critique of the Chernobyl accident might shy away from the discourses – the papers, reports and bulletins – of the hard sciences, and instead focus on political/cultural representations. Thus, this quasi-scientific evaluation of the phenomenon attempts to fill what this thesis (as a whole) identifies as a lacuna present within social science's understandings of the accident and RBMK no4.

The final key text is Morton's (2013) *Hyperobjects: Philosophy and Ecology after the End of the World*, a philosophical outlook on the new types of objects created in the present epoch. Generally speaking, Morton's work seeks philosophically to explain how these 'hyperobjects' permeate throughout society, complicating existence by means of their unique materiality. At root, the notion of hyperobjects is used here to explain certain aspect of the Chernobyl accident, in that it highlights how RBMK no4's evasive accomplice of radiation facilitated its infamy, and helped to engender the actions account for within the empirical core of this research. Finally, a short discussion will be provided, focusing on Schatski's (2002) notion of the site, and Shaw's (2012) concept of eventual geography, analytically bountiful conceptual constructs that have helped guide the methodological crosshairs of this research.

2.1 The wider theoretical landscape: have we ever been modern?

So, where to begin? – why the middle of course – in Latour's so-called 'Middle Kingdom' (Latour 1991). His pinpointing of the inherent paradox and subsequent conceptual blind-spots within the modernist constitution is captured by the assertion contained within the title of the text, *We Have Never Been Modern* (1993), paving the way to his amended 'constitution', a nonmodern constitution, one seeking to provide a permanent place of residence for the hybrids that the moderns have created but denied 'official' existence: 'quasi-objects' that invariably lead to the collapse of the moderns' 'invincibility'. Thus, what follows is a retracing of Latour's key insights into the modern constitution, with reflections on the ramifications of these theoretical negotiations, as well as on the resulting methodological techniques. This account will be supplemented by an exploration into the varying spatialities implicated within ANT, the full picture then being the one that shapes the logic of how the empirical chapters that follow – and the respective spaces therein tackled – have been conceived.

2.1.1 The Modern Constitution.

For reasons that will become clear, attention must first turn to separation: the ever present insistence of modernism. Latour contends that what he terms the 'Modern Constitution' insists upon a distinct separation between Nature and Society, all endowed with capitalised first letters to emphasise their supposed importance. This divide between the natural and the social worlds, for the moderns, forms two distinct poles which must always be kept separate in order to be comprehensible. Moreover, the very concept of 'modern' also indicates a separation in terms of the passage of time, as the word's meaning designates a break from what has come before. Latour argues that this 'chronological separation' evokes notions of combat, in that the moderns (of the later twentieth century) have been victorious by defeating the premoderns and that their 'victory' has led to the start of the modern era. This split results in one of many asymmetrical aspects of this school of thought. Latour goes so far as to state that the hypothesis of this entire intellectual project is that "the word 'modern' designates two sets of entirely different practices which must remain separate if they are to remain effective, but have recently begun to be confused" (1993,10). These two practices are the works of 'translation' and the works of 'purification'. The former is the process whereby new forms of mixtures are created from different aspects of nature, culture, and technology — the merging of these things creates hybrids, not quite natural nor totally social. The latter engenders what are taken to be two ontologically distinct zones with humans (Culture) on one side and nonhumans (Nature) on the other. To be truly modern one has to consider these two practices separately. Latour creates two terms, firstly to represent the product of the former process, networks; and secondly to summarise the character of the latter, "the modern critical stance" (1993, 11).

For Latour, the two practices of translation and purification within the modern constitution form a distinct spatial configuration. The first dichotomy between the two works of purification takes place 'on the top' and for Latour this division is vertical. The second is spatialised horizontally, situating it 'below' the first; this is the space where the works of translation occur. Thus, the first dichotomy keeps Nature and Culture, human and nonhuman, independent from each other, and the second keeps the works of translations distinct and separate from the first. Latour deploys a host of diagrammatic styles to visualise his arguments throughout *We Have Never Been Modern* (1993) to great effect — figure 2.1 delineates the works of purification and transition.

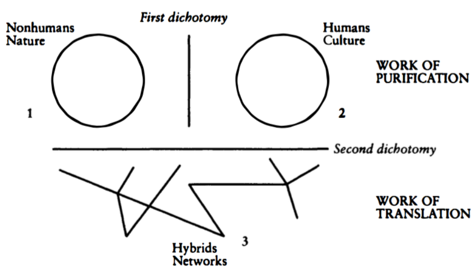

Figure 2.1: Latour's graphical delineation of the works of purification and translation (Latour 1993, 11)

This constitutional double separation results in the moderns' denial of any link between these two processes; but this denial, for Latour, is untenable. He argues that we must reconnect all that has been separated within the modern critique, both 'above' and 'below', and only then will we have the ability to conceptualise a space for the complex mixtures of Nature and Culture – hybrid objects that have multiplied in number and complexity in the current epoch. At this juncture Latour introduces the prospect of the methodological concept of comparative anthropology. The fundamental ideas of such a method are alien to anyone who considers themselves to be truly modern, as only 'premodern' societies, ones which do not separate Nature and Culture into two distinct poles, can be analysed using the tenets of anthropology. Hence, to deploy a form of comparative anthropology to assess the current epoch, one must admit that they are not modern and embrace the works of purification and translation in tandem. In this sense, then, the present project is a pre-modern (or better amodern) anthropology of the Chernobyl event.

This is not the place to elaborate upon the intricacies/guarantees of the Modern Constitution, but one crucial insight made by Latour alights upon the works of mediation, the processes which happen 'down below'. The Modern Constitution facilitates the work of mediation, but it does not permit the conceptual merging of elements of Nature and Society, for the guarantee is in place to keep them permanently separate. Latour (1993, 34) argues that "the essential point of this modern Constitution is that it renders the work of mediation that assembles hybrids invisible, unthinkable, unrepresentable". Thus, the hybrids that are created by mediation are therefore denied any form of official existence by the moderns, even though their constitution facilitates their creation. The dual processes of translation and mediation are closely linked to Latour's concepts of intermediaries and mediators, covered below. For now, attention must be trained upon mediation. Within *We Have Never Been Modern,* Latour is rather vague when he cites the concept of mediation, with a fully realised account of his process of mediation provided in the years following this seminal text. His concept of "technical mediation" (Latour 1994) should be viewed as a means of clarifying the relationship between humans/machines and the process of mediation itself. In order to grasp this phenomena, the concept of translation must be brought into the equation. For Latour (1994, 32), translation is a "displacement, drift, invention, mediation, the creation of a link that did not exist before and that to some degree modifies two elements or agents". Here, translation is the mutual modification between two entities, and thus mediation is now understood to be the product of an association – the link between, for instance human and machine. A mediation is therefore an association that alters an entity, changes its form, orientation or ontology. The association between a master craftsman and a log of wood enacts a detailed mediation that results in a chair, table or bookcase.

So what does all this mean? It may be accepted that if anyone considers themselves to be truly modern, they must believe in the promises laid out in the Modern Constitution. Latour has gone to great lengths to show the fallacy of such a belief, for, if we are convinced that the works of purification and mediation have no relation, that Nature, Society and God are forever to be kept separate, we realise that the Constitution creates two unsolvable paradoxes and denies the hybrids engendered during the processes of mediation any form of official existence (as Nature and Society never mix). Crucially, for this research, if we were to take the moderns at their word, believe fully in their doctrine, we would be unable to conceptualise the very object under analysis, the ruined, thoroughly 'impure' RBMK no4 of the Chernobyl NPP. As previously stated, the moderns, due to their need to break from all that has come before, cannot accept that any form of anthropology could be conducted in their era. However, the methodological framework of comparative anthropology would allow this piece of research firstly to represent the networks which swarm around the Chernobyl's RBMK no4, and secondly, as a consequence, to reassemble how this nuclear non-human has travelled.

2.1.2 Hybrids and quasi-objects

This section above has accounted for how the Modern Constitution allows for the proliferation of hybrids and guarantees their denial of official existence, and now attention turns to the significance, make-up and the importance of nonhumans/quasi-objects. Latour argues that the proliferation of hybrids has "saturated the constitutional framework of the moderns" (1993, 51), and at the outset of the book he uses the example of the hole in the Ozone layer to illustrate the potential make-up of a hybrid, shedding light on the heterogeneous – as in varyingly composed, materially multiple – networks that contribute to the engendering of this mixture of Nature and Society. The degrading of the Ozone above the physical Poles is a mixture of both the Natural and Social worlds. Swarming around it is a vast network, one which connects subjects, objects, places, institutions, governments and international agencies.

Objects are crucial to provide an ontology for hybrids. To avoid the pitfall of transcendence and the condemnation of these hybrids, and their networks, to the realm of epistemology, Latour introduces, and furthers, Serres's (1993) concept of 'quasi-objects' and quasi-subjects. In short, this conceptual apparatus awards elements of hybrids a material form: Serres provides the example of a game of football to highlight that quasi-objects are neither Natural nor Social, but are in fact a delicate mixture of both. He argues that the ball used in a game of football draws people together into particular sets of relations, also creating subsequent relations with other humans and nonhuman entities. Latour elaborates on these relationships thus:

> A ball is not an ordinary object, for it is what it is only if a subject holds it. Over there, on the ground, it is nothing; it is stupid; it has no meaning, no function, and no value.... Playing is nothing else but making oneself the attribute of the ball as a substance. The laws are written for it, defined relative to it, and we bend to these laws. (1993, 225-226)

From this extract we can begin to see the importance of quasi-objects and their potential to influence human action. Our (human) collectives are formed around objects; they bring them together and hold us in space. Each object has its own set of rules and functions which impact on how we interact with space, the object itself, and also each other. Levels of complexity inherent within an object's configuration/manufacture do not automatically translate into higher amounts of impact or influence on human subjects.

Size is another issue: "Could the macro-actors be made up of micro-actors?" (Latour, 1993, 121). Latour poses this question in relation to examples of huge institutions or companies, but the question still has relevance when posed in relation to quasi-objects, for their inclusion as actants within his theory forces one to ask identical questions to those directed at human actors. The quasi-object at the heart of this research, RBMK no4, when taken as a whole, was colossal in size and complexity; it drew thousands of people to it on a daily basis, and the only way for it to function safely, and correctly, was through the labour and care of skilled professional actors. Thus, these people were fundamentally connected to the object: they fed it, emptied it, repaired it, lived in it and risked their lives for it when it was sick. The purpose of drawing attention to 'global' companies was Latour's means of highlighting that the myth "of the soulless, agent-less bureaucracy" (1993, 121) offered nothing conceptually. The only way to explore the networks that stretch across the globe is to find instances when they are materially situated — physically sited and arranged — within space. Only then will we be able properly to represent their networks. This process is identical for the quasi-object of RBMK no4 — its physical spread of fallout was global, as was its ideological reach, yet one can readily identify the points in space where it 'touched down'; this could be its radioactive fallout, or when its agency produced nodes of human action in distant sites. The site of the plant in Ukraine is where it all began, the space that played host to the geoevent, to be elaborated upon shortly, and the importance of the micro level actors/actants within this site must be reassembled in order to achieve a 'faithful representation', one showing as much fidelity as possible to the heterogeneous materials, composed within the site and then subsequently scattered elsewhere.

In an attempt to visualise what effect these quasi-objects have on the Modern Constitution, Latour uses another diagram (figure 2.2). As the proliferation of hybrids (down below) results in the saturation of the traditional split between the two poles, Latour indicates that we must resist the moderns' desire to think only in horizontal terms and instead chart quasi-objects on a new vertical line, one which awards them a place in *both* of the processes of translation/mediation and purification. This insight is vital to the entire quest to award hybrids and their quasi-objects an official place of residence, reconnecting of all that is separated in the Modern Constitution. The moderns have always practised the two processes of mediation and purification, but they have never been explicit about the interrelationship between the two of them. By thinking in both longitude and latitude terms, the tracing of any given hybrid's coordinates will render this relationship visible, a core goal for the empirical chapters that follow.

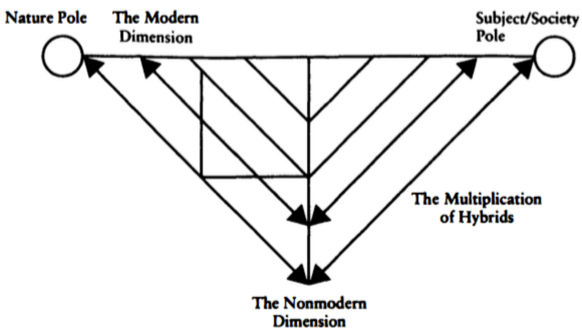

Figure 2.2: Latour's graphical delineations of the proliferation of hybrids and quasi-objects (source: Latour 1993, 51)

2.1.3 Expeditions in the 'Middle Kingdom'

Until this point my comments have alluded to Latour's rejection of the inherent double separation of the Modern Constitution. Thus, armed with this logic, the ability to recognise the importance of the Middle Kingdom is awarded through careful adaptation:

> ...the middle, where nothing is supposed to be happening, there is almost everything. And at the extremes - which according to the moderns house the origin of all forces, Nature and Society, Universality and Locality - there is nothing expect purified agencies that serve as constitutional guarantees for the whole. (Latour, 1993, 123)

Imperative to this thesis project is the realisation that Latour is not calling for a 'revolution', because, according to him, the term has lost its impact. The notion of 'adaptation' is a far better means of articulating what he hopes to achieve. As he seeks to create the context for the application of a symmetrical comparative anthropology, he insists that the works of translation must be taken into account. This mode of thought reverses what the moderns proposed, for the works of purification should be treated as a final outcome, entities to be critiqued/analysed and not the starting point of enquiry. Nature and Society are therefore now, alternatively, cast as satellites revolving around collectives which produce things and people. They revolve around the Middle Kingdom. The general rule of symmetry has been partially explained above: "Nature and Society are to be explained. The explanation starts from quasi-objects" (Latour, 1993, 95).

This expedition into the Middle Kingdom, as should be clear, is a sustained assault on many principles of the Modern Constitution, for in its place Latour proposes what might instead be called the Nonmodern Constitution - drawing inspiration from the premodern (in their readiness to live and think hybridly) and also from those who can be deemed postmodern (in their readiness to critique modernity's stark binaries). From all nonmoderns, he wishes to learn about the non-separability of things and signs, the multiplication of nonhumans and their belief in transcendence. The Nonmodern Constitution offers certain guarantees. The first insists upon the non-separability of quasi-objects and quasi-subjects. This guarantee places the work of mediation in the very centre of the two poles of Nature and Society, and through this promise networks come out of hiding: "The middle kingdom is represented. The third estate, which was nothing, becomes everything" (Latour, 1993, 140). The second guarantee is in place to stop us transgressing back into the realm of the nonmoderns, and it allows us to retain the first two guarantees of the Modern Constitution; with one crucial recognition, that they are not to be separated. In other words, Nature can be transcended (during the final analysis) and Society can be immanent. This guarantee is in place so that the networks rendered visible by the first guarantee are identifiable and controllable. The third guarantee is focused around temporal flow. It states that we should be free to combine associations without being restricted by having to choose between "archaism and modernisation, the local and global, the cultural and the universal, the natural and the social" (Latour, 1993, 141). This represents a distinct break from what Latour identifies as modern epistemology as we are no longer tied to 'pre-packaged' forms of knowing. The fourth guarantee is articulated as the most important. It states that the clandestine nature of the proliferation of hybrids is to be replaced by an agreed upon production system. In other words, it allows them to inhabit the now visible Middle Kingdom. This move results in the meticulous ability to assess and sort the proliferation of quasi-objects and the networks that swarm around them, and, crucially, all of this can now happen 'officially' if we, researchers, recognise and believe in the Nonmodern Constitution.

Through these proposed guarantees, we, researchers, can begin to identify the analytical purchase designed into Latour's philosophical project. Objects, particularly of the non-human varieties, have traveled a long and difficult road in their quest to be taken seriously within social science research, and *We Have Never Been Modern* signals an influential turning point. For the study of the Chernobyl accident, the ability to identify and assess a quasi-object is of imperative significance, as the entity at the centre of the network in question is a nuclear non-human, a hulking mass of nuclear grade metal and concrete, a crucible of irradiated material, a bewilderingly complex combination of Nature and Society. Thus, when the significance of objects to this research is articulated, we can clearly see the value in reassembling the philosophical negotiations of Latour, as they render visible the means to award such non-humans a legitimate place within an analytical endeavour. The relevance and proof of this claim will of course only become plain in the empirical chapters that follow.

2.2 Uncertainties, associates and the wolf of context: the ANT methodological toolbox

Much has been spoken about ANT methodology and this section delineates its key tenets. *Reassembling the Social: An introduction to Actor-Network Theory* (Latour 2005) masterfully represents Latour's logic during the middle years of his intellectual project. Within the book's pages, the approach of ANT is meticulously articulated, philosophically legitimised and relatively accessible practical directions are provided. Akin, if certainly not identical, to Marston *et al's* (2005) flat ontology of scale ANT should be viewed as a 'bottom up' approach, a talisman of the material turn, one which facilitates the material landscape's influence upon the narratives, theories and concepts of the 'meta level' (rather than the opposite way around). Of primary concern to Latour are the theoretical blockages that restrict an ontologically insistent study, or, in this instance, an ANT analysis. He argues that these blockages must be conceptually bypassed prior to analytical departure; and, when this new perspective is achieved, an ANT scholar can trace the material connections/associations of the network in question.

The first of these theoretical blockages revolves around the ambiguous epistemological construct of 'the social'. Latour (2005) argues that the traditional, or 'default', approach in sociological research evokes a distinct conceptualisation of 'the social', one that affords it the ability to be utilised as an *explanatory* term. This movement away from epistemological 'explanatory concepts' is a key feature of Latour's intellectual project. For Latour, this understanding of the social has facilitated its use as a stabiliser of sorts, a type of 'material' that comes pre-packaged with ties, expectations and ready made 'contexts' to account for the social aspects of non-social activities and phenomena. In other words, the social pertains to a domain somehow separate from the specific and detailed claims of economics, psychology, geography and so on — one that has the slippery ability to insert itself into the existence of any phenomenon, 'social' or non, in an attempt to explain aspects of it. This fundamental theorisation of the social is the bedrock upon which the commonsensical approach within sociology is erected: Latour refers to this default method as a "sociology of the social" (2005, 10).

By insisting that the social can be viewed as a material form of glue that holds our societies together, *as well as* a stabilising agent, the concept designates two separate and entirely different things: "first, a movement during a process of assembling; and second, a specific type of ingredient that is supposed to differ from other materials" (Latour, 2005, 1). This taken-for-granted tenet of the default approach creates *troublesome* ontological issues: asking how the mysterious entity of the social can indeed form a distinct domain of reality, one which has the ability to stabilise and explain non-social phenomena, and yet its composition is not comprised by elements inherent within the periodic table? It has no *objective* existence. It could be argued that regarding the social in such a manner places it in the same perplexing category as dark matter and energy — astrophysicists think we know that it exists, we think we know it has an effect on us, but we are unable *scientifically to* identify its ontology.

Latour's means of combating these issues inherent within the default method of sociological enquiry is the creation and promotion of a second approach. He states that his new mode of analysis emphatically rejects the tenets of the first. Akin to his 'recalibration' of Nature and Society within *We Have Never Been Modern (1993),* he is now attempting to show that the social can *never* be used as an *explanation*. To put it rather crudely, it must always itself be explained, a reversal of usual social-scientific thought. Gone are the ideas of the social being a circulating adhesive capable of grouping society, to be replaced with the recognition that the 'social' is what is *glued* together by a heterogeneous range of connections and associations. In other words, the social is never to be conceptualised as a 'thing' or 'entity', but instead treated as "*a type of connection* between things that are not themselves social" (Latour, 2005, 5). This philosophical negotiation is important for the wider ANT project, as it characterises the very character of the approach; that is, phenomena cannot be *explained* by means of non-identifiable epistemological constructs, but rather these once 'useful' theoretical apparatuses are precisely what have to be *explained* through material analysis.

Latour (2005, 20) calls this new approach a "sociology of associations". He proposes that sociological enquiry should be focused upon tracing connections and associations in an attempt to describe a reassembling of the social. This new intellectual project has the ability to cast aside the belief that hidden forces lurk behind our reality and formation of social aggregates. It problematises the often taken-for-granted understanding of what it means to be social. It is important to state that the rejection of said 'hidden forces' results in a much slower paced form of research. The habit of appealing to the 'social' or 'society' demands "a sudden *acceleration* in description" (Latour, 2005, 22), but ANT studies do not enjoy such luxuries. A sociology of associations does not traverse the landscape through means of 'aviation', imposing grandiose meta-level framing prior to field work; instead, it has to hike the trails and back roads of the material landscape — taken seriously its piper and vents, bodies and biomes — in its attempt to reach the analytical goal of a full(er) description. This version of sociology results in a fundamental reversal in the role of the actors within ANT, as it is believed that *they* are the only ones with the legitimacy to define, order and reassemble the social.

One of the fundamental ideas of Latour's intellectual project is the differentiation between 'intermediaries' and 'mediators'. The origin of these concepts occurred in *We Have Never Been Modern* (1993), but Latour has finessed their conceptualisation, significance and utilisation over the years (Latour 2005, 2009, 2010). For Latour, an intermediary is a person or object that transports meaning without transforming it. He links this concept to that of 'black boxes', introduced in *Science in Action* (1987). As intermediaries do not transform or translate the information that they transport, we can view an intermediary as a provider of a faithful representation, a singular 'voice' supplying a validated meaning. Mediators, on the other hand, are arguably more interesting, being the translators of input; and we must always assess their specificity and positionality when attempting to assess their input-output nexus. To put it rather plainly, ANT scholars are most interested in mediators, while practitioners of the default approach, the Modern Constitutionalists, seek to research intermediaries. This statement is a little misleading as both approaches could be looking into the same phenomena or actor. Thus, in an attempt for clarity, we must understand the importance of how one treats or recognises the varying tools and methods deployed by the actors during the construction of social aggregates. For ANT, mediators are the rule and intermediaries are the rare exception. Indeed mediators can be 'dangerous', as in the case of the Chernobyl NPP accident, where the Soviet Union and the station's chief operators routinely mediated the severity of the accident for their own interests.

A recurring theme within ANT, and its methodological toolset, is the insistence that anything accountable within the research process must be visible or at least accessible to the senses (to be sense-ible). Therefore, if one seeks to account for an agency that has affected the action of an actor, it cannot be 'hidden behind the scenes' – to appeal to such an entity would not be in keeping with the ANT corpus. If someone mentions an agency, then, if they consider themselves to be an ANT scholar, they must provide an account of its resulting action, which can be achieved by means of following the observable traces left by both the agency and the action. Latour (2005, 53) summaries this insight as follows: "If it has no vehicle to travel, it won't move an inch, it will leave no trace, it won't be recorded in any sort of document". This recognition is linked to the aforementioned 'infra-language' of analysts and the rejection of the belief that they are the only ones capable of possessing the conceptual skills to identify a context. By awarding situated actors the 'privilege' of accounting for the agencies that have influenced their actions, an ANT scholar lets the actors do the work. Latour offers the concept of "practical metaphysics" (2005, 51) in a bid to characterise this new mode of enquiry.

Latour introduces a third uncertainty that awards the objects of our collectives a form of agency, a radical departure from the sociology of the social. For the study of the Chernobyl accident, this third uncertainty is of key relevance, for the dominant actor within the network here is an object, otherwise referred to as the nuclear non-human. Akin to his attempts at achieving a symmetrical departure point for analytical enquiry in *We Have Never Been Modern* (1993), Latour not only elaborates upon the agencies within objects, but also casts the work of power and domination in the same manner as the social – they need to be explained. Much like the two poles of Nature and Society, the asymmetries created by power and domination should be the end product of the research process, never confusing the "*explanandum* with the *explanas*" (Latour, 2005, 63). To paraphrase Latour, if we are to account for the asymmetries of power and domination, without appealing to 'social forces', we must expand our analysis to other actors, namely objects. These non-social entities lend their ontological existence to our collectives, and they are the things that to help bind them together. If ANT is the method of following the actors, then we, as researchers, should extend this injunction to assess how they negotiate the material landscape, assessing how they interact with the many objects which they use and with which they live in tandem.

Latour's further concept of 'actant' finds conceptual footing when queries about the agency and 'legitimacy' of objects come into focus. Latour states that any *thing* which has an effect on the state of affairs but has yet to be subjected to figuration is an actant. Laurier and Philo state that the purpose of this term is to set it apart from actors, thus "signal[ing] a definition of the term that does not rule out nonhumans as valid (social) agents comparable with humans" (1999, 1048). One of the fundamental tasks that an ANT scholar must perform before the analysis has begun is the identification of who and what form of the grouping surrounds any form of action. This is not to say that ANT wishes to group participants into a neat preordained 'system', but is more of a practical methodological point. In order to begin a research project on any topic, prospective 'participants' must be identified. Once the exploration of the actors has begun, the pool of actors (both human and non) will be directed and expanded by the data collected in the field. The inclusion of non-human actors thus creates a symmetrical framework for ANT's conceptualisation of actors. That said, ANT is not proposing a symmetry between the philosophical 'standing' or value of humans and objects: they are not somehow taken to be exactly the same, equivalent order of 'stuff' in the world. All that is being proposed is a symmetrical starting point which rejects notions such as the priority of human intentionality and a material realm filled simply with causal relations.

The key issue presented by the inclusion of objects within the concept of actors is that they only help trace social connections intermittently, since their actions may be continuous or discontinued, and the nature of the object determines to which of these modes of action it conforms. ANT must be able to account for when objects give 'weight' to social ties, as well as the points when nonhumans fade into the background. Much like invisible agencies and non-performative groups, if an object leaves no trace and has no discernible effect on the state of affairs, it cannot be accounted for by ANT. To counter this issue, Latour adds several tools to the ANT repertoire as a means of rendering visible the multiple associations when objects act, but when their visibility is compromised by time, space or mediators.

One such tool is attention to occasions when objects break. When an object rapidly changes its ontological existence, it also flips from intermediary to mediator. In keeping with the Chernobyl example, when the station was functioning as designed, its input/output nexus could be classed as a 'black box' – uranium went into the core and, electricity was produced by the turbines (an incredibly simplified version of the process of creating energy from nuclear fission). Other than the actors tasked with feeding and caring for the station, it faded into the background and the network swarming around it was limited. However, after the disaster its 'black box' status was relinquished; its input was the same but the products of its output were markedly different from its original design. Now its network grew exponentially to encompass a vast range of native and foreign actors and mediators. Thus, the explosion and resulting change in the station's agency mobilised actors within its material landscape, but also attracted a vast new network of mediators, all of which left vivid traces of the new associations as they attempted to mitigate the accident.

2.2.1 Latourian tools (and questions of scale/space)

A material turn demands the rejection of epistemological categories, a priori conceived categories with vague world referents, and a reclamation of ontological concerns. Marston *et al's* (2005) critique of scale and consequent promotion of a site-based ontological approach to geographical enquiry sought to reject the epistemological categories of local/global when understood 'hierarchies' (the latter determines the former) and somehow clearly distinct from one another — a task that Latour has also taken up. He states that, although we inhabit a 'local', we cannot deny that many influences within such a spatial zone come from other, more distant sites. In other words, agencies from distant sites transgress space and inhabit 'local' settings. Latour hence argues that to concern oneself with local 'interactions' is not befitting of an ANT enquiry (Latour 2005, 2011), perhaps a slightly strange statement about a theory that insists upon the following of actors within the material landscape, but to view it in such a simplistic manner does not do the logic justice.

Once again, this logic returns to Latour's critique of the default approach, the Modern Constitution and its desire to 'meta-up' in a bid to explain aspects of the material world. Hence, when a sociology of the social meets a phenomenon within the 'local' setting, it seeks to explain it through the imposition of context; but this move, for Latour, is untenable as the abstracted (analyst-led) contextualisation has no ontological existence. Thus, the analysis is dragged from the material world into the epistemic planes of the meta or the global. This binary between the two scalar constructs offers nothing analytically and results in a flawed approach. For, when the research focuses upon the 'local', a contextual setting is seemingly required, and when said structured context is invoked it necessarily departs from the real and embodied experiences of the actors (or actants). This micro/macro debate renders several modes of enquiry lacking, but the fundamental principles of ANT provide a solution. If one is to consider the actor and the network that swarms around it simultaneously, the ability to traverse space from the one site to another is granted. The traces left by the interactions and associations of actors not only link previously 'local' and 'global' concerns, but also facilitate the actor-led contextualisation of their situation. This results in Latour arguing the impossibility of staying in either of the binary opposites:

> If there is no way to stay in either place it simply means that those places are not to be reached – either because they don't exist at all or because they exist but cannot be reached with the vehicle offered by sociology. (2005, 170)

What this means for ANT is the identification of yet another controversy upon which to feed. The desire to 'scale jump' from the micro to the macro should be viewed as an opportunity for ANT. As it is impossible to inhabit either of them for any length of time, they instead form an entirely different phenomenon. The pace of an ANT enquiry is slow and methodical, since the scholar has to trail constantly across the nooks and crannies of the material landscape; thus, appealing to the macro scale is another means of speeding up enquiry, as it represents an attempt to *explain* by means of a prior epistemological construct. If we accept that interactions within the material landscape are overflowing with diverse and far-reaching agencies, they can therefore be traced by means of their application and consequential existence in distant sites/spaces. Subsequently, this process articulates the network during the methodological practice; that is, the act of tracing associations between actors discloses the network, hence resisting the desire to contextualise.

The rejection of meta-level explanations thus renders the research two-dimensional; for, if one cannot appeal to the vertical plains, in essence a rejection of the hierarchical model of scale, one must gain ANT-compatible data within the flatlands of the material landscape. In other words, through the insistence on accounting for the ontological, the desire to appeal to the epistemological is quelled, and the analysis can reside comfortably within the material realm. The final part of this section is hence tasked with elaborating on the last three Latourian methodological tools, finalising the methods deployed in this research. The first tool seeks to localise the global, the second attempts to redistribute the local, and the final utensil of the ANT toolbox connects the sites of the first two tools.

The first tool for connecting sites together involves following the processes of translation covered above. This alludes to the necessity of following mediators as they transport translations across space and consequently describing the networks in which they participate – a time-consuming and difficult empirical exercise. The main analytical pitfall that must be resisted here is indeed the desire to 'jump' up to an analyst-designed context. As ANT prefers to inhabit a flat, two-dimensional material landscape, the transportation metaphor finds further relevance, for the ANT scholar must be able to identify the means, or vehicle, through which any action is transported. "The tyranny of distance" (Latour, 2005, 174) implicit within a flat ontology of scale is the main methodological stumbling block that ANT has to overcome, and Latour creates a series of '*clamps*' as a means of keeping said flat ontological framework. These clamps do not describe what is being mapped, they simply facilitate the process and, rather, they are simply practical tools.

The first clamp is the concept of the *Oligopticon* (2005, 181). This tool provides a framework for mapping the relations between the micro and the macro scale. ANT seeks to dispel the belief that the micro scale is encased within the macro, but instead promotes the logic that everything happens on the micro scale and that the traces left by the interconnectivity of sites are the key empirical data for ANT. Thus, a "structure-making site" (2005, 176), one which would have traditionally been classified as playing an important 'macro' role, *must* be shown to have linkages and connections to other sites. If these links are invisible, or non-existent, it ceases to be a structure-making site. In other words, to achieve relativist scale, we have to describe a site as being neither above nor below the interactions that we seek to explore – there is only flat interconnectedness.

It is no surprise that ANT stemmed from the study of the hard sciences as there is no better example of this process. A laboratory is an incredibly 'small' spatial site in the grand scheme of things, but what it produces could have the potential to connect sites across the entire world. A university research facility which finds the cure for cancer will in effect connect all cancer treatment centres of the world. To categorise these types of sites, Latour introduces the concept of Oligopticon*,* an inversion of Foucault's (1977) use of Bentham's Panopticon. Oligopticons are the exact opposite of the idealised prison, being sites that see too little to feed the obsessionalism of those in charge and the paranoia of the inspected, but what they do see they see with unrivalled clarity and focus. Their narrow view can lead to their easy identification in space and time, and as long as the ANT scholar can trace how their translations overcome the tyranny of distance to describe how they are connected to other sites, they form the first clamp of flatness. Thus, Latour (2005) states that, if one can see the effects of their connectedness, an ANT scholar should ask stock questions about the material location of their existence in a bid to locate the Oligopticons.

The second clamp is referred to as *Panoramas* (Latour 2005). These methodological constructs grant actors the privilege of defining their own context and relative scale, consequently rewarding the analyst with data during the process. Latour argues that scale is in effect a zoom-like function and one that should be put in the hands of the actor situated in the site/network. It is through their use (or misuse) of said function that the importance of Panoramas comes into focus. Unlike the Oligopticons, Panoramas see everything, but they also see nothing at the same time since what they delineate is a mediated version of events. These could take the form of a documentary, a newspaper article or editorial, a travel guide, or a report of an international body seeking to account for the radioactive deposition from RBMK no4. Panoramas use the zoom function of scale to connect the material landscape to macro level forces, consequently 'educating' on how to consume them. Their totalising view of the state of affairs should be taken seriously and handled with care. They are local sites that translate information and (mis)represent it in a manner which fits the ideological viewpoint of their creators; an ANT analysis must always treat Panoramas as complex and dangerous mediators. Once again, in a bid to capture the presence of a Panorama, ANT must ask the same materially locating questions covered above.

The two tools of the Oligopticon *and* Panoramas allow ANT studies to localise the global within the two-dimensional flatlands of enquiry and trace their associations and connectedness. Of crucial importance is the realisation that, if these two tools are rigorously deployed the asymmetries of power, hierarchy and domination can be described as a final product. This move results in the reclamation of 'context', again only as a final product, never an explanation. The Latourian project of seeking symmetry rears its head once again when dealing with the second tool tasked with redistributing the local. For if the global/macro does not exist unless it has been brought back to the material level, how is the local generated? To answer this question, Latour states that the local has to be "re-dispatched and redistributed" (2005, 192). In other words, his promotion of a doubly symmetrical process paves the way for the realisation that the connectors between the two processes comprise an entirely new phenomenon for research purposes.

Latour argues that simply believing local interactions to be shaped by existing elements tells us nothing about their origin or nature. Thus, if one rejects this belief, an ANT study can then search for the materially traceable existence of connections between sites of production. This mode of thought must recognise that the course of action is invariably affected by a diverse range of human and, more importantly, non-human actors. An ANT scholar must reserve the right to pursue a wide range of agencies, and to resist the temptation to pre-impose a limit on what can and cannot be considered an actor or actant. Latour introduces the terms of *articulators* or *localisers* (2005, 194) in an attempt to articulate how the influence of local sites can be transported into other ones. This transport can be achieved through the agencies of non-humans as they are bestowed with a form of quasi-agency from their human creators. For example, the seats at a football stadium partially dictate the actions of the people who attend. This point connects the spaces of the architect's workshop and the designer's agency to that specific location, linking the two local sites through the movement of subtle, yet effective agencies. These background agencies begin to highlight the analytical pitfall of face-to-face (human) interactions, as every local space embraces a diverse range of influences and agencies which will affect the actions of the actors in question.

The final methodological tool of relevance here is focused around how the ANT corpus connects the sites relocated and redistributed by the previous two tools. The first tool/move relocated the macro/context into the local, which allowed it to form a two-way process. The second tool/move allowed for the transportation of sites into one another through the diverse agencies which span space and time. Now that we have an understanding of the necessity of utilising these two tools, Latour states that the prize for ANT becomes visible, a third phenomenon. Sites have been implicated and transformed into actor-networks, and so the connections and their vehicles come into focus. Now it is hypothetically possible to account for every translation, mediation and assembling without jumping to a meta-level explanation. The price that must be paid for this new ability is slow and meticulous research. Nothing is taken for granted and everything must be reassembled.

In the context of the Chernobyl accident and the analysis of the transgressions of RBMK no4, ANT provides a scholar with the necessary theoretical and methodological tools to take seriously the agency of this infamous nuclear non-human. The method's insistence upon situating analysis within the material realm, alongside its lineage within science studies (Latour 1987), allows a research project to resist the temptation of trying to *explain* this complex scientific/engineering phenomena by means of social theory, and instead facilitates the following of the actors drawn to the accident. These actors are highly educated within scientific/engineering domains, and they are therefore professionally attuned to the intricacies of the accident. What must indeed be apparent at this stage is that ANT promotes a following of actors, as they are the best placed people to reassemble the situation within which they find themselves. In the case of a techno-scientific accident of the magnitude of Chernobyl, this direction finds relevance to the effect that the researcher's role is then largely as a mediator; an act of constant slow retrieval, reordering and redescription, seeking to preserve material ontologies in the face of demands for epistemological apriorism.

2.2.2 Latour's clarification

The methodological apparatus covered thus far could be classed as 'middle Latour'; that is, the delineation of ANT from the works he produced during a distinct period of his intellectual project. He has, however, provided numerous clarifying statements in the years since, culminating in his most recent book *An Inquiry into Modes of Existence: An Anthropology of the Moderns* (2013). This section is tasked with reinforcing the researcher's appropriation of ANT by means of Latour's later clarifications – most notably, his refined network concept. Latour's *Modes of Existence* is a masterful call to arms and summation of his intellectual project. It could be viewed as an ambitious request from a philosopher to his readership to help him to complete the work that he started, but which he is unable to finish, alone. In order fully to prepare his potential research assistants, he further hones his methodological apparatus, and most relevant to this research is his updated delineation of a network – his network – and how it can be used for analytical purposes:

> The advantage of the term, despite all the criticisms to which it has been subjected, is that it can easily be represented in material terms (we speak of sewage networks, cable networks, spy networks); that it draws attention to flows without any confusion between what is being displaced and what makes the displacement possible (an oil pipeline is no more made 'of' gasoline than the internet is made 'of' emails); and, finally, that it establishes such a powerful constraint of continuity that a minor interruption can be enough to cause a breakdown (a leak in an oil pipeline forces the operator to shut the valves; a three-meter displacement in a WiFi zone results in a lost connection: there is no longer any 'network coverage') (Latour, 2013, 31)

From this extract one can deduce that a double movement exists, in that a network is the product of a network. Thus, when viewing a network in this manner, two distinct stages appear: one of construction and one of functionality. Take, for example, the Ukrainian electricity national grid, prior to the Chernobyl disaster. This electrical network was indeed not made of electricity, but rather comprised a vast and complex melée of wires, transformers and power stations. If, say, one sought to study the electrical usage of each household in Kiev, this network of things, object and non-humans, would have to be functioning as designed, while the end product of the labour would be the second stage; that is, the network of electricity itself that fed into each household and the consequential human practices that it enabled.

Latour (2013, 32) clarifies this simple, yet somehow deceptively elusive, distinction by stating that "what circulates when everything is in place cannot be confused with the setups that make circulation possible". Thus, the *identification* of which network is under analysis is of paramount importance, although Latour states that a comprehensive ANT analysis will incorporate both senses of a network. This conceptual reconfiguration provides ANT with a more accurate reticle, but it is of limited applicability to this research. Rather, the analytical purchase is found when Latour details situations when networks, in the second, complete sense, break, and the two stages subsequently converge. When the supply of a service is unexpectedly cut off, the logistical network tasked with performing the delivery of the service is brought into focus, and attention moves on to its ontological form. When situations like this occur:

> Everyone then sets out to explore all over again the set of elements that have to be knitted together if there is to be a 'resumption of deliveries'. Have you anticipated that link between the Ukraine and cooking your risotto?... Behind the concept of network, there is always that movement, and that surprise. (Latour, 2013, 35)

The need to be analytically accurate and mobile is a prerequisite of a research project of this kind; in that, different domains must be visited, depending on the 'state' of the network under scrutiny – network of construction or functionality. In order to maintain freedom of movement across the network, Latour states that one must remain attentive to the heterogeneity of the visible associations and identify the types of *value* that are circulating within the network in question. It is at this juncture that the concept of risk becomes central.

Risk, in the discourse – the arguments, the texts, the pronouncements – of both the social sciences and the hard sciences, permeates throughout every empirical chapter below, each dealing with a different domain's identification, articulation and mobilisation of risk. Every action taken after the explosion was tasked with mitigating risk on some level, be it minimising the risk of radioactive exposure to the surrounding populations (or further afield) or the mitigation of the risk of another mechanical malfunction. Thus, when fused with RBMK no4's new agency, risk, in its numerous manifestations, *is* the value of the network. It is the finalised property that *explains* the diverse and complex nodes of actions accounted for throughout this research. Actor A travels to site X, she then speaks to Actor B and subsequently performs action Y upon object Z. This action is technical in nature and involves assessing the materiality of object Z, and the end product of this series of associations between humans, sites and non-humans is the *translation* of the accrued information into a risk assessment format; that is, the language that connects the ontological to the epistemological, the nuclear non-human to the risk.

The final tool of relevance here is the significance that Latour places upon *passes* and *continuities/discontinuities*. Each domain of concern has its own language and systems of conveying meaning, and Latour uses the example of the legal domain to illustrate this point. For Latour, a 'pass' is an association that only members of that domain can identify; that is, the transportation of value in a format that only trained actors can understand. Latour (2013, 39) states that:

> ...a pass particular to law; something that leaps from one step to the next in the work of procedure or in the extraction of means. In short, there is a particular type of connection, of association, that we are going to have to learn how to qualify.

In this instance he is referring to meaning that is conveyed in a manner that usually only lawyers can understand, feeding into his arguments around continuity and the reaching of it through a series of discontinuities. Latour argues that, for an outsider to a domain, continuity is reached by means of a seemingly unconnected series of discontinuities – the language/terminology that is deployed is obtuse and, without prior knowledge, said outsider is unable to decipher how continuity has been reached. A probabilistic calculation of a specific risk represents a continuity; for instance, the end product of a series of actions. These actions are performed by actors trained with the expertise required to make the calculations for reaching this end goal. When this process is either discursively represented, or even merely heard during a conversation between said actors, the linkages between these specific actions, discontinuities and the finalised continuity will not readily present themselves. For the outsider, the puzzle of how A + B + C = D cannot be solved without first understanding the meaning of the passes being made. The only way to render visible the intricacies of the riddle, and to identify the values of the associations, is to envelop oneself within the discourses and literatures of the domain under scrutiny. In the case of this research, it resulted in my immersion in the teaching of nuclear engineering, nuclear physics environmental physics, and diverse sciences of radiological protection. This process has resulted in my ability to identify how A + B + C = risk.

2.2.3 The era of the nonhuman

As the central entity of this research is a vast machine, the nuclear nonhuman of RBMK no4, more attention must be placed upon philosophical projects that take seriously the role of objects within worlds. This subsection tackles a possible lacuna within the literature covered in this chapter, as it assesses the works of influential human geographers operating within the area of object-orientated ontology, scholars who explore the turbulent existence of nonhumans within both geographical research and more general philosophical life. An influential figure within human geography's movement away from reductionist dualisms (and also embracing of ANT) is Hinchliffe, who has written extensively within the realms of posthumanistic geographies. In his book *Geographies of Nature: Societies, Environments, Ecologies* (2007), Hinchliffe approaches the heterogenous topic of 'Nature' and its complicated relationship with human geography. At the outset he states that, "Simply put, this book is about how nature is 'done', how it is practised, how it materialises as an active partner in and through those practices" (Hinchliffe 2007, 1). Generally speaking, the book is Hinchliffe's attempt to argue a place for nature in human geography, in so doing its conceptualisation through a distinctly Latourian lens, and arming the discipline with new theoretical and methodological equipment to analyse 'nature' in the more-than-human era. Hinchliffe argues that the term 'nonhuman' should not be viewed as a direct reinscription of 'nature', but rather signals "a worldliness of worlds, suggesting that cultures and societies are shaped by more than human geographies" (Hinchliffe et al 2005, 3). The emphasis, once again, is to break from the binary choice between human action and the 'pole' of nature, and instead to pursue an understanding of the interaction between the worlds of humans and nonhumans. For Hinchliffe (2007), the traditional possibilities of independence and dependence – that is, a nature that is independent of human agency, and one that is a construct of society – have to be replaced by a realisation that these supposedly once separate constructs are in fact two sides of the same coin. He argues that "there are numerous ways in which the world is read that are socially sensible, but the world itself carries on regardless... once you get beyond these surface scratches, nature stays the same" (2007, 36). These philosophical negotiations are influenced by Latour's thinking on the separation of the poles of Nature and Society, emphasised by Hinchcliffe's routine citing of Latourian arguments. He reaches similar philosophical conclusions to Latour, with regards too how ideologies surrounding nature and society have traditionally been used as a means of *explaining* situations, phenomena and events in the world. He consequently argues for a methodological trajectory that problematises these once static explanatory categories. Here, the metaphor of *hybridity* takes on a renewed importance:

> ...it allows for novelty to be produced. Novelty that is not reducible to component parts. Indeed, parties do not simply interact to produce a new (impure) form. Rather, in relating, the parties and the product must change too... Nothing remains unaltered in the event of relating. (Hinchcliffe 2007, 51)

The concept of hybridity thus facilitates the recognition that both human and nonhuman entities are moulded and shaped by relations, becoming hybrid through interaction with others. This interest in more-than-human geographies has prompted Hinchliffe to tackle several areas that feature distinct mixtures of humans and nonhumans, ranging from: explorations on 'living cities' (Hinchliffe and Whatmore 2006) that reorientate traditional urban analysis, so as to take seriously the desire to abandon spatial/philosophical divisions; to ecological examinations of urban areas and their green spaces (Hinchliffe et al 2005), as well as the wider landscapes (Whatmore and Hinchliffe 2010). His more recent works explore the concept of biosecurity, an ambiguous construct that, once again, firmly places nonhuman agency within the realms of human existence and practice.

For Hinchliffe, the active practices of biosecurity vary from country to country, but at root, the term refers to the actions taken to limit the transgressions of biological nonhumans into the human population (Bingham *et al* 2008). The term 'biosecurity' can be used as a means of justifying, characterising, explaining or rationalising practices that limit and order the lives of a population. In the UK, the foot and mouth outbreak represents a prime example of biosecuritisation of livestock, human practice and policy (Hinchliffe and Bingham 2008). One could say, for example, that, in the interests of 'biosecurity', livestock from farm A, B and C, must be culled in order to limit/eradicate the potential human exposure to a transmutable disease. The term becomes an umbrella means of grouping together heterogeneous nodes of action that span several spheres of social life, but ultimately result in limiting the movements of humans and nonhumans. Thus, as with so many aspects of this research, Latourian logic is relevant; that is, analytically, the term 'biosecurity' must never be used as an *explanation*. Instead, it is precisely what must be *explained,* its network charted and actors followed to reassemble the relations and associations that co-mingle to produce the restrictions on human and nonhuman existence.

The above UK example features a mixture of human and biological nonhumans, notably livestock, and aspects of the Chernobyl disaster could be classed as action pertaining to 'biosecurity' matters. Chapter 5 accounts for the material spread and deposition of caesium from the NPP across Europe, or, in other words, the invasion of a nonhuman into the spaces of human populations. The resulting measurements of deposition, the mapping process, and the subsequent restrictions on livestock, and farmland, could be framed as actions tasked with insuring biosecurity in the face of a radioactive nonhuman agent. Furthermore, chapter 6 accounts for the LNT debate – the gold standard of radiological protection and the debate around its continued usefulness. This debate features a melting pot of issues, interests and agencies, all focused around the biological impacts of ionising radiation at low doses. This phenomena links nonhumans (ionising radiation), the human population, and a vast array of national, international and research institutions, all in a delicately interwoven network of biosecuritisation.

Diseases are of primary concern within biosecurity matters, and as a result they permeate Hinchliffe's work. He argues (2013, 201) that the emergence of diseases:

> [l]inks together financial institutions, consumer habits, populations growth, environmental change, large food corporations, viruses, genetic and breeding technologies, chickens, and so on.

For Hinchliffe, the agency of an emergent disease impacts throughout a host of domains, the reverberations of which are felt by humans and nonhumans alike. This attention to how a microscopic nonhuman, that of a disease, can dictate large swathes of human action renders visible the necessity of taking seriously the impacts of nonhumans, big and tiny. Traditionally, such a role has been only been filled by a human actor, a sentient being that is capable of tailoring its action output to operate in, through and among the spheres of existence mentioned above. More-than-human geographical research, particularly that which explores biosecurity matters, highlights that the agency of some nonhumans can be even *more* impactful than that of their human counterparts; in that they cannot be reasoned or bargained with, and come packaged with very real, and dangerous material consequences for biological entities. Thus, in some rare instances, nonhumans should be viewed as at the very centre of being: without such a recognition, their damaging impacts can be underestimated.

RBMK no4 is the central actant within this research — a broken mass of twisted steel, nuclear grade concrete, graphite and uranium. It cannot speak, ponder the purpose of life or independently move any of its appendages. It is not a sentient being, but, as this research highlights, its lack of interventional human agencies has not stopped it traveling and impacting upon its sentient counterparts in countless different ways. It has shattered and created worlds, helped mould new paradigms of risk, evoked biological mutations in human populations, and sparked debates within the sciences. It is one of the most influential human-made nonhumans that the world has ever witnessed, a status 'earned' by means of its material potency and the all-encompassing nature of its travels. More-than-human geographical research has highlighted that biological nonhumans, mere garden plants and trees, can 'direct' human action in surprising ways. This research adds to the opposite end of the spectrum, accounting for the not-very-surprising tsunami of action created by an explosive malfunctioning nuclear reactor.

2.3 Risky Networks: a meeting of Beck and Latour

This section marks a more tailored discussion, one tasked with encompassing the overarching theme of this research project. The impacts of the Chernobyl accident are heterogenous, and its travels extensive. To the lay public, the stricken nuclear power station adopts many guises, but this research project is uninterested in popular appropriations of the accident; rather, it is focused upon the more clandestine — or at least specialist and often somewhat obscure — domains of science, engineering and bureaucracy. These areas of actions and interest are separated in many instances, but within the context of RBMK no4's network, the concept of risk crosses their boundaries.

Risk: an ambiguous, broad and contested concept. Elusive in definition and powerful in application, this term has sparked the interests of the social and hard sciences for decades, at least since the Second World War. It is constructed within scientific, economic, political, social and moral spheres, and the agency of the final product is consequently interwoven throughout them all (Beck, 1992, 1995, 1999; Jarvis 2007; Mythen 2004; Wynne 1996). The risk industry has engendered a diverse and complex lexicon of systems, parameters and procedures tasked with identifying the adverse potentiality within a situation. Generally speaking, this assemblage revolves around the scientific construction of risk; that is, the quantitative assessment of the probability of an event occurring in a specific location from a specific hazard (Cidell, 2012). Risk in this guise, moreover, has arguably now become widely disseminated through many facets of what is specified as 'risk society.

The 'risk society' perspective, the major contribution of Beck (1992, 1995, 1998, 1999), and furthered by the likes of Giddens (1998), has become hugely influential within the academy and beyond. The focus of the risk society entwines the process of modernisation within a climate of ever-escalating risks produced by the omnipresent development of technology. Due to its notable spread throughout the academy and given its analytical clout, the basics of Beck's theory shall be covered in detail below, and indications given as to where it can be of use to this study.

An interesting aspect of Beck's thesis, highly relevant to this thesis, lies in what prompted him to produce this approach, with several scholars (Mythen 2004; Wynne, 1996) citing the Chernobyl disaster as the driving force behind his ideas. As Beck's thesis was being written in the late-1980s, when the nuclear industry was routinely deployed as a spectre of catastrophic risk, it does not seem too much of a reach for this claim to be accepted. In a relatively unknown essay, published in 1987 but originally written in May 1986, a few weeks after RBMK no4 exploded, Beck himself evaluates the impacts of the Chernobyl disaster upon his thesis. Titled, 'The Anthropological Shock: Chernobyl And The Contours Of The Risk Society' (1987), this short piece affords a glimpse into Beck's reasoning around an event previously unseen in human existence. He had been working on the book *Risk Society* (1992) for two years prior to the accident, and the book already contained his prophecy about the catastrophic potentiality of nuclear technologies, but he was forced to incorporate the new 'case study' into his text, which then went into "its fourth edition after only nine months" (Beck, 1987, 154). Chernobyl provided Beck with a vindicating example, the 'ideal' worst accident imaginable, for transporting his thesis into the wider public consciousness and to strengthen his arguments. Even here, then, it is possible to see evidence of how RBMK no4 'travelled'. Therefore, it is fitting that Beck represents the conceptual core of the present project's attention to risk. To underline, each of the empirical chapters features an area of RBMK no4's network, and these segregations each speak to a different world of risk; that is, varying aspects of the accident that impacted upon different avenues of society's new 'risk industry',as well as upon the concept as a whole. It will be possible to trace the entanglements of Chernobyl with the making of risk: of risky worlds, risky actants, perceptions and calibrations of risk, and even glimpse of how risk gets politicised.

Throughout his career, Beck built upon his initial thesis; and, in order to capture this evolution, my account will predominantly focus upon *Risk Society: Towards a New Modernity* (1992) and *Ecological Politics in an Age of Risk* (1995). Beck was one of the first sociologists to identify the paradox of late-modern society, that the driving force behind the increase in risk was the very advancement of technology, science and industrialism, as opposed to risk being abated by scientific and technological progress (Jarvis 2007). Beck's approach seeks to account for the untethering of social institutions, epistemological changes in the natures of risks, and the subsequent cultural experiences of them (Giddens 1994; Mythen 2004), all in the face of this historically unique context. What Beck also reveals is the pervasiveness of the concept, its purposeful appropriation from the top and felt impacts at the bottom; that is, the articulation/calibration by institutions/governments and their imposition of 'risks' guidelines upon their subjects and citizens. This pervasive spread of the notion of risk has resulted in its central placement within globalising society, and its utilisation is a means of control, regulation and power (Elliott, 2002). For Beck, risk is of course not the same as destruction; rather, it represents the spectre of a potentially destructive outcome. The concept of risk is a means of rendering visible a reality which could come to pass, one which would have adverse consequences, and the *discourse* of risk — that is, the discursive representation of said findings — "ceases to apply when the potential catastrophe actually occurs" (Beck 2000, 213). This is an important aspect of the concept of risk in general; risk is the epistemological rendering that seeks to account for an ontological reality *as-well-as* a future material happening. This is a peculiar stance to take, especially when one takes into consideration Beck's repeated deployment of the nuclear industry as a bedrock example for the risk society. Granted, the epistemological purchase of a risk discourse will be eroded when an event occurs which it was attempting to mitigate; but, rather than simply 'ceasing to apply', said risk discourse may evolve, mutate and become of even greater significance in light of such an accident. As will be shown in later chapters, developments of this kind are the result of heterogeneous nodes of actions which produce version '2.0' of a risk discourse.

As a means of situating his conceptualisation of risk, Beck charts its progression through a Eurocentric history and subsequently maps out three epochs. These periods in human existence are characterised by the risks to which they were exposed and the nature of their creation. The supposed transition from one epoch to another was prompted by both the compositional make-up of the risks experienced and structural changes within society. Fundamental to this process, and the risk society approach in general, is Beck's differentiation between natural hazards and manufactured risks. Natural hazards, or 'acts of God', were a feature of the pre-industrial society: these damaging exhibitions of the natural world's power caused large-scale issues for the early phases of human existence as the technology to mitigate them had yet to be invented (Beck 1992, 97). For example, a flood would have washed away entire towns due to the lack of infrastructure to defend against the risk, and drought could ruin an entire year's food supply due to the lack of irrigation and/or weather predictive systems.

The movement into the 'industrial society' or first modernity, which roughly encompassed the first two-thirds of the twentieth century (Lash 2000; Mythen 2004; Mythen & Walklate 2006), saw the above-mentioned natural hazards supplemented with a host of human-made risks. Practices and products which arose at the time were not considered risky, but with contemporary scientific hindsight can be identified by their dangers. Activities such as smoking, drinking and occupational injuries as a result of a newly industrialised economy thereby characterise the changing nature of risks bound into structural changes within society. Finally, two-thirds of the way into the twentieth century, human existence entered into the full-on 'risk society' (Beck

1992, 1995), otherwise referred to as second modernity. This ominously titled 'epoch of risk' is epitomised by a human quasi-mastery of natural hazards, but a limited ability to mitigate the potentially devastating impacts of human-made, or 'manufactured', risks. Beck has been criticised for neglecting the societies of the Global South as they have yet to achieve said levels of mastery over natural hazards (Jarvis 2007). Thus, his writings can indeed be viewed as Eurocentric, especially when one considers that some developing countries use nuclear power stations and produce large amounts of air pollution.

Beck states that the main differentiating aspects between manufactured and natural hazards risks are found within creative processes that provide them with ontological existence. In other words, "the looming power of gods and demons … differs essentially from 'risks' in my sense since they are not based on decisions, or more specifically, decisions that focus on techno-economic advantages and opportunities and accept hazards as simply the dark side of progress" (Beck 1992a, 98). Thus, Beck is seeking to set up a classical modernist dichotomy between Nature and Society, the former being the wrath of 'our little blue space ship', and the latter represented by complex nodes of human actions which encompass a host of spheres of society, resulting in the creation of a technology laden with destructive potentiality. Being a modernist, and unlike Latour, Beck cannot actively situate his analysis within the realm of hybrid objects; rather, Beck routinely deploys the ambiguous term 'technology', a conceptual blindspot which will be covered below. Manufactured risks of a catastrophic nature are, for Beck, unique to the latter part of the twentieth century, and the increase in techno-scientific development is fundamentally entwined with the spread of risk, a factor encapsulated by Virillio some years prior to Beck's initial thesis:

> Every technology produces, provokes, programs a specific accident … The invention of the boat was the invention of shipwrecks. The invention of the steam engine and the locomotive was the invention of derailments. The invention of the highway was the invention of three hundred cars colliding in five minutes. The invention of the airplane was the invention of the plane crash. I believe that from now on, if we wish to continue with technology (and I don't think there will be a Neolithic regression), we must think about both the substance and the accident. (Virillio 1983, 32)

This chillingly poignant prediction of reality at the time of writing, and into the foreseeable future, chimes with Beck's risk society. For Beck (1992, 22), the movement into the risk society entailed, "a phase of development of modern society in which the social, political, ecological and individual risks created by the momentum of innovation increasingly elude the control of protective institutions of industrial society".

Beck postulates several conceptual tools to aid within the risk society approach, and his three core hallmarks of risk, or 'pillars of risk', as Mythen conceptualises them (2004; Mythen & Walklate 2008), are of use to this project. The first is geographical in nature and focuses around the mutation of risk's relationship with time and space. In the pre-industrial and industrial epochs, Beck (2000) argues that the forms of risks experienced were spatially and chronologically contained. Flood water will dissipate and a volcano's emissions have a limited horizontal reach, and furthermore the timescale required for these damaging impacts to fade is contained within the lifetime of a human being. As Western societies entered into the period of the risk society, they implemented various structural changes, including infrastructural defences against natural hazards. Take, for example, the Netherlands' world-leading flood risk assessment systems, tasked with supplementing the natural sand dune barriers (van der Hoeven *et al* 2009), or Japan's 'earthquake architecture' philosophy, which sees the design of a building being tailored to mitigate the potential risks associated with an earthquake (Charleson & Taylor 2000). These two examples highlight both the identification of natural hazards and the formation of engineering solutions to minimise them.

Things are complicated when moving into the risk society, as manufactured risks, according to Beck, are no longer spatially or temporally limited. Beck (1987, 1992) leans heavily on the Chernobyl example to illustrate this point, arguing that RBMK no4 represented a new paradigmatic manifestation of environmental risk. It can readily be seen why he utilised this example, as prior to the disaster the world had never 'publicly' witnessed an accident of this magnitude, scope and legacy. The fallout's atmospheric journey across Europe paid no attention to imaginary human-geographical boundaries thousands of feet below, and the chronologically expansive nature of fission products rendered the disaster a risk for both current and future generations. In other words, RMBK no4 stands as the talismanic standard bearer of the risk society, the destructive monolithic monument to unchecked techno-scientific advancement and the unwelcome ruination of the environment by its invisible byproducts.

The second characterising 'pillar' of the risk society is the truly catastrophic nature of manufactured risks. Once again, this increase in destructive capacity differentiates them from their natural counterparts. Beck (1992, 1995) classifies three "icons of destruction" as the primary technological perpetrators with such catastrophic potentiality: nuclear power, environmental despoliation and genetic technology. The prospective dangers of these technologies "transcend temporal, spatial and social boundaries and have the potential to fundamentally change or even annihilate human life, at least as we know it" (Johns & Werner

2008, 784). Indeed, the current climate of rapid technological advancement has led to an environment where the risks associated with a potential malfunction have massively outpaced society's safety nets – the epitome of the risk society.

Beck's use of 'nuclear power', as opposed to militarised nuclear technology, is perhaps a strange choice, one which could be explained by the powerful effects of RBMK no4's agency at the time of writing. As will be shown in later chapters, the testing of nuclear weapons has deposited more fission product into our biosphere than Chernobyl and Fukushima combined. Furthermore, the sole purpose of these weapons is mass destruction on a biblical scale. Everything accounted for by the risk society thus far could be applied to the weapons proliferation race, arguably with greater analytical accuracy. Two entire cities were wiped out by two of the smallest, and most technologically 'ignorant', nuclear weapons. Furthermore, a host of 'appropriated' islands in the Pacific were literally obliterated during the testing of US and UK hydrogen bombs, and the invisible legacy from both examples still rides the global airwaves today. Surely the risks associated with the deployment, proliferation and geopolitical posturing of the Cold War were of far greater significance than the accident in Ukraine? A plausible explanation for Beck's choice could be the clandestine nature of military decisions and the development/use of atomic technologies. Networks both rarely visible within the civilian nuclear industry. Regardless of this empirical niggle, the use of nuclear power as an icon of destruction was understandable and even justifiable, especially in light of the Chernobyl disaster.

Beck's arguments about risk's regulatory systems will now be covered, partially because such systems become crucial in later chapters in thus thesis. Such systems marks a shift from the ontological heritage of any given risk to focus instead upon the human organisations tasked with ensuring social security, including techno-scientific protocols which seek to minimise the probability of a risk occurring. The introduction of entities of this nature, be it the IAEA or the global network of Institutes of Regulation and Risk within the financial sector, marks the nexus where the concept of risk becomes entangled with other actors' interests and, subsequently, their agency. Since its inception, risks within the risk society are, generally speaking, quantitatively calculated and intrinsically connected to scientific logic/practice. As mentioned at the outset of this section, the scientific construction of risk is based on the probability of an event occurring in a specific location from a specific hazard (Cidell, 2012). Primarily, this sectioning of risk identification within the realms of science/engineering is due to the complexity of the hybrid objects, after Latour, capable of producing a catastrophic accident. It is safe to assert that only a qualified nuclear engineer possesses the knowledge to assess a nuclear reactor, and only a biologist with decades of experience can evaluate a programme of genetic modifications. Nonetheless, Beck (1995, 135) argues that "no one any longer has privileged access to the uniquely correct way of calculation, for risks are pregnant with interests, and accordingly the ways of calculating them multiply like rabbits". From this claim, it can be deduced that Beck believes in a heterogeneous trajectory of risk calculation, entailing many actors and maybe actants, and in many instances he is correct. However, his lack of detailed scientific knowledge and elaborative examples can arguably weaken this argument.

As he routinely cites the nuclear industry as a fundamental risk creator within his approach, it might be expected that Beck cover forward several different methods tasked for calculating the probability of ruptures within steam inlets, or associated with stress testing the heat exchange mechanisms, and so on. His 'external' critique of a scientific practice, solely from a social science perspective, erodes the force of this logic due to the lack of situated examples from the industries that he is seeking to critique. Indeed, he provides scant examples from scientific and/or engineering practices to legitimise his critique, but rather makes sweeping generalisations in order to construct his social theory. His suggestion regarding how scientific domains calculate risks in a strictly deterministic manner may be appropriate within some technological areas, but the nuclear industry has utilised probabilistic safety assessments (PRA) since the 1970s in the United States (Kopustinskas *et al* 2005; Lee & McCormick 2012) and upon the entire fleet of Soviet reactors after the Chernobyl disaster (INSAG 1992, 1996; EBP 1999). Granted, this is a case-specific example, but it does foreground the inadequacies of meta-social generalisations about the scientific realm. Counter to Latour's suggestions, Beck fails to follow the actors encased within the 'risky industries' that he is seeking to critique, never really allowing them to influence his theory as a 'bottom up' approach, but instead he is imposing meta-level narratives devoid from, or devoid of, any situated knowledge. As a result, Beck is open to many of the critiques that Latour directs at mainstream social science, as explained earlier.

Throughout his analysis of regulatory systems, Beck argues that they have been constructed to dissipate responsibility, a new defence mechanism of the risk society to deal with catastrophic risks. Dense legal and bureaucratic protocols cloud the pathways of allocating responsibility, and parties implicit within the risky activity subsequently appropriate a calculation of risk which suits their interest. Beck is highlighting that the lack of universally accepted methods of calculation within a risky situation allows actors to squirm out of any responsibility which may be levelled against them. The 'power' of this relationship lies in the difficulties of proving a causal relationship between, say, thyroid cancer and C-137, a necessity within a court of law. Thus, when viewed through this lens, the construction/calculation of risk incorporates the interests of powerful actors, and consequently their agencies will direct actions to produce a mediation of 'risk' which renders *invisible* any causal connection between them and the issue. This type of hierarchical appropriation of risk is typical of the governmentality approach (Defert 1991; Castels 1991). Such a polemical mediation of an ontological reality has relevance within Chernobyl's network; namely, the Linear no-threshold debate surrounding the 'acceptable' dose of low level radiation, a debate that will be extensively accounted for in chapter 6.

As mentioned above, 'defining' risk is difficult due to the ambiguity of the phenomena that the concept is seeking to represent. As the scientific community has been endowed with the status of risk identifiers within the risk society, a complex nexus is created between it, policy-makers and the general pubic. It is difficult to account for the mediations between policy-makers and their scientific advisors, but the relationship between them and the lay public is readily accessible. Beck (1992) sets up a dichotomy between scientific rationale and its social counterpart. The actions and practices of the former are governed by the dominant technical means of calculating the risk in question, with the attempt to achieve objectivity, and the latter comprise the lay public's subjective evaluations of the 'top down' risk assessment by means of their lived experiences. Beck (1992, 28) goes on to argue that "the two sides talk past each other. Social movements raise questions that are not answered by the risk technicians at all, and the technicians answer questions which miss the point of what was asked and that feeds public anxiety".

If the rather totalising rendition of this two-way relationship is glossed over, one can identity a fundamental issue within the risk society, and a root cause of social scepticism is thereby rendered visible. The perception of risk varies dependent on the levels of 'education' within the scientific discipline that can represent it, and the mediated accounts produced by experts of said discipline can, unintentionally, result in negative reactions from the lay public. In other words, the communicative bond between risk technicians and the lay public can either be inadequately formulated or appropriated by the agencies of 'guilty' parties in a bid to disperse blame. Thus, these nodes of actions are crucial battlegrounds within the risk society as they are the points where meaning – that is, the representation of a situation which requires technical knowledge – is publicly disseminated, and where a conflict over its legitimacy and/or accuracy can then ensue. Such matters are central to the later chapters of the thesis.

Attention will now turn to Beck's arguments about the production of environmental risks. Within the risk society, due to their exponentially damaging potentiality, the hybrid objects that can produce manufactured risk present new forms of environmental dangers. These aspects have been covered above, and the reason behind accounting for the production of environmental risks is to address the elephant in the room – that of Beck's modernist persuasion in light of this project's belief that 'we have never been modern' – with the end goal of reconciling Beck's approach with the research project's methodological framework. Central to Beck's entire scholarly enterprise is an unwavering separation of Nature and Society, as he believes that "the risk society begins where nature ends" (1998, 10). As covered in sections 2.1 and 2.2, which introduced the Latourian logic/methodology, the modernist project separates Nature and Society into two discrete poles, refusing to acknowledge the Middle Kingdom. Beck (1995) tentatively states that the techno-scientific advancements which prompted entry into the risk society have eroded the historically assumed boundaries between the two, but he does not situate his analysis within the realms of objects. Rather, he speaks in terms of epistemological explanations, rather than accounting for the ontologically networked hybrid objects which materially contain and produce risks.

Due to this research's adoption of ANT as its method and conceptual underpinnings, the hybrid objects created by the merging of Nature and Society are of primary concern. Every idea from Beck's project covered thus far can be of use when reassembling Chernobyl's network, but his epistemological trajectories must be related to their ontological component parts. Risk is a constructed concept, a representation of – but also on intervention in – a material reality and future, one which can be materially reassembled. Simply deploying the spectre of the Chernobyl disaster to vindicate one's argument without actively accounting for the object of the reactor, or the intricacies of its material travels, runs the risk of engendering hollow 'explanations'. Conversely, Latour's long-term fascination with 'science' has resulted in his ability to disclose the networks which construct knowledge of that nature, and subsequently to provide the social sciences with a means of either critiquing or supplementing the process. Without this form of analytical methodology, a social science project that is predominantly dealing with scientific risk calculation will lack any form of ontological application. In other words, the material domains of a risk, its object of potentiality, and the nodes of scientific action tasked with representing it: those elements should all be essential components within risk research. Otherwise, the analysis resorts to gazing upon a phenomenon that it dimly understands, producing a worryingly asymmetrical account. Bromley (2000) argues that Beck's account is weakened by his routine use of ambiguous terminologies, such as describing Chernobyl as a 'global threat', when in reality its sphere of influence barely covered all of Europe, and by his lack of detailed attention to the physical technologies. Thus, an approach which seeks accurately to represent the ontology of a risk, as opposed to merely accounting for the supposed ‘mediation’ of it, would afford the risk society approach an ontological scientific foundation.

Taking the meta-aims of the research into consideration, partial meeting of Latourian and Beckian projects can be made at a point post-ANT description; that is, once a materially attuned account of a risky *object* has been completed, in this instance of RBMK no4 of the Chernobyl NPP, its trajectories through time, space and different domains can be shown as inexplicably interlinked with the ideas of the risk society. Such a meeting should be seen as an attempt to ‘counter’ the main critiques of each; these being the limitations of a pure ANT description, and Beck’s inability to focus upon the ontology of hybrid objects. Hence, reassembling Chernobyl’s network of risk, from object, to immediate aftermath, to atmospheric spread and finally to regulation, provides in effect an ontological backbone, for better or worse, to Beck’s talismanic example — his ‘ideal’ worst disaster imaginable to exemplify his tenets of the risk society. The representation/calibration of a risk should be viewed as the result of a heterogenous node of action which incorporates both human and non-human actors, as well as a host of mediations across several levels of society.

2.4 Radioactive hyperobject

> We are living textbooks on global warming and nuclear materials, crisscrossed with inter objective calligraphy. (Morton, 2013, 88)

Morton’s philosophical construct of hyperobjects is rooted in object-orientated ontology (OOO), and it seeks to provide an explanation for the widely distributed entities that co-inhabit the world with humanity. At the heart of this philosophical performance is another dilemma about the modernist project, a recurring theme within this research’s theoretical backbone. Whereas Latour believes that we have never been modern, Morton (2013, 19) argues the stance that we *have* been modern, “and that we are only just learning how not to be”. The catalyst behind this paradigm shift, for Morton, is hyperobjects. RBMK no4 may initially be conceived as a ‘hyperobject’, but Morton delineates several interrelated qualities to identify such an object, and several of these parameters are incompatible with the nuclear non-human at the heart of this research. Thus, another aspect of the object/event is brought into focus, and with it the philosophical *explanation* of *how* and *why* the travels of RBMK no4 have engendered the actions to be accounted for within Chapters 4, 5 and 6.

For Morton, hyperobjects feature five innate interrelated qualities: viscosity, nonlocality, temporal undulation, phasing and interobjectivity. This is not the place to provide an extensive account of each, but rather the key components of each will be touched upon and the connections between the concept and Chernobyl will be covered. Viscosity, as the name suggests, is linked to the attractiveness of hyperobjects; that is, the inescapable means by which they attach themselves to people and other things. For Morton, a hyperobject's viscosity is closely linked to its relationship with time, in that time is argued to emanate *from* hyperobjects, rather than a continuum through which they merely pass. Morton (2013, 33) references Chernobyl as a means of illustrating this point, citing the "uncanny dead zone, The Zone of Alienation" as an ideal example of how hyperobjects produce time bubbles from their ontological form. The entity of radiation/radioactive materials is routinely used by Morton as a means of legitimising his philosophical negotiations, to brilliant effect when delineating his concept of viscosity:

> A good example of viscosity would be radioactive materials. The more you try to get rid of them, the more you realise you can't get rid of them. They seriously undermine the notion of 'away'. Out of sight is no longer out of mind, because if you bury them in Yucca Mountain, you know they will leach into the water table. And where will that mountain be 24.1 thousands of years from now? (Morton, 2013, 36)

Thus, radioactive materials 'stick' to our society – once they are created we simply do not know what to do with them, outside of the standard burial practices. They are viscous to the point that society simply seals them in casts and commits them to the hands of time in designated spaces, that in turn feature a strange form of temporal distortion. Akin to the Chernobyl zone, sites of long-term storage for nuclear materials become imprisoned by the effects of the hyperobject's emission of time. They are shaped by it and locked into a binding relationship that extends centuries longer than humanity has been resident on our blue spaceship. In other words, the hyperobjects of radioactive materials condemn their space of residence to an eternity of exclusion by means of the emission of temporality from their ontological form, thus binding the space to their half life.

Morton's concept of nonlocality is slightly more difficult to grasp than viscosity, but it still has relevance to this research. He uses the Chernobyl and Fukushima accidents as examples to highlight how hyperobjects are nonlocal, in that their radiation:

> ...bathed beings thousands of miles away in unseen alpha, beta and gamma particles, as radioactive specks floated in air currents across Europe and the Pacific. Days, weeks, months, or even years later, some humans die of radiation sickness. Strange mutagenic flowers grow. (Morton 2013, 38)

Granted this example does highlight how these nuclear accidents have been massively distributed, but the simple fact remains that the objects responsible for the distribution of the hyperobject of radiation *can* be locally situated. These nuclear non-humans still represent the central point of a radioactive network that spread around the globe. Regardless, Morton's detailing of the link between the nonlocality of hyperobjects and *causality* creates an interesting connection to the empirical work of Chapter 6; that is, the LNT debate. He argues that hyperobjects inhabit a Humean causal system, where associations, correlations and probabilities are our primary means of identifying the entity – the favoured lexicon of a nuclear risk technician. Hence, due to the complexities of the systems required actively to identify the hyperobject, it is difficult to provide direct proof of a causal link between it and another phenomena. As an aside, this aspect of Morton's hyperobjects is linked to one of the tenets of Beck's (1992) risk society, in that the current system of risk prevents the ready identification of responsibility/causality between a risk and a perpetrator.

As a means of engaging a practical avenue of this tenet, Morton introduces the notion of local manifestation; that is, specific points in space-time where the agency of the hyperobject directs human (or nonhuman) action, perception and thought. Once again, Morton uses a nuclear related example to illustrate his point; in this instance, 'Little Boy', the atomic bomb dropped on Hiroshima. Morton (2013, 49) argues that when a bomb survivor produces a testimony of the day in 1945, it represents a "local manifestation of the bomb", and that the constraints of human physicality and memory temporally displace the bomb, thereby rendering it distant and close at the same time. When viewing hyperobjects in this light, each of the empirical chapters of this thesis represent local manifestations of the hyperobject of RBMK no4's radioactive ontology. These nodes of action are created by, and fully orientated towards, the hyperobject, in a variety of near and distant localities. They facilitate a means of physically identifying the hyperobject in space and time through its interactions with human actors. Morton (2013, 53) argues that "(i)n some sense, cancer is the physical body's expression of radioactive materials. Such is the force of the hyperobject radiation". If this logic is extended to the empirical works of this research, these nodes of action are the expressions of the Soviet Union, environmental scientists, the atmosphere and radiological protection institutions of RBMK no4's radiation. Their geographical placement in space is therefore a local manifestation.

Temporal undulation is the third identifying characteristic, and it is rooted in the science and philosophy of space-time. In effect, we are all enveloped by hyperobjects, due to their massive distribution, but their ontology is so time-stretched that it is difficult actively to understand them. Hyperobjects exist within epochs so massive, in comparison to the totality of human existence, that they inhabit a domain of space-time that cannot be fully grasped. Once again, Morton (2013, 58) uses the hyperobject of radiation as a means of vindicating this aspect, arguing that:

> The half-life of plutonium-239 is 24,100 years. These periods are as long as all of visible human history thus far... I have decided to call these timescales the horrifying, the terrifying and the petrifying.

Thus, when attempting to render visible the timescale associated with the hyperobject of radiation, and, crucially, operationalising the practicalities of accommodating for the half-life of radioactive materials, these 'horrifying' adjectives neatly characterise proceedings. Every action accounted for within this research is tackling an entity with a vast half-life, one that will outlive every human being alive today.

The temporal undulation of hyperobjects leads to futural elements. Because, for Morton, time is not a vessel in which objects float, but rather an emission from hyperobjects themselves, he argues that it is theoretically possible that an object could exert a backwards causality on other entities. In other words, future causality flows backwards into the present, with the spectre of the future looming into the present. This philosophical negotiation can help to explain the actions of human actors within the present when dealing with the temporal undulations of a hyperobject, as the future needs, deviances and dangers presented by the elongated ontology of the object result in sustained nodes of actions in the present. Thus, as shall be covered in Chapters 4, 5 and 6, every action was tasked with catering for the future within the present. The actions of these empirical chapters took place in 'a present', but were tasked with mitigating risk, or dangers, that would arise in the future. The needs of the present were clear and present, but, due to the next tenet of hyperobjects, the future cannot be ignored.

The four interrelated dimensions of hyperobjects postulated by Morton are classed 'as phasing', in which regard he argues that hyperobjects occupy a high-dimensional phase space that makes it impossible for humans to 'see' them in a regular three-dimensional setting. This inability of humans physically to 'see' hyperobjects is thus linked to the practices/actions required actively to account for their presence and ontological structure. Morton (2013, 73) states that:

> Process philosophy helps us visualise how high-dimensional entities execute. Thus, a slightly upgraded way of seeing hyperobjects would be the plot or graph... The trouble is that we cannot help but fail to see such high-dimensional entities when they are plotted this way. Software 'sees' them for us, then we see data or slices of that phase space, rendered in some way to make it usable.

This logic is pertinent to the hyperobject of radiation, and the necessity of using objects to render it visible. This passage helps philosophically to explain such unavoidability, and can thus be extended to the actions presented within Chapter 5 — the act of airborne gamma ray spectrometry (AGRS). This practice was performed as a means of 'seeing' RBMK no4's radioactive dispersion across the landscapes of the UK, and the data accrued was then plotted on maps and in graphs. This series of actions was tasked with combatting the phasing element of the hyperobject.

Due to the phasing nature of hyperobjects, and the necessity of scientific practices to render them visible, mathematics inevitably also plays an important role. Morton argues that mathematics must be embraced when dealing with hyperobjects, but they must be viewed as a Latourian *mediation*. The mathematical processes of the sciences are a means of representing a hyperobject, and thus, by definition, a delineation that can be open to mediations. Morton here seeks to inject a modicum of critical thought into proceedings, and to direct methodological focus on to who, why and how a hyperobject is mediated through scientific practice/mathematics. Furthermore, his insistence upon embracing scientific mathematical processes, within a more 'socially' orientated research project, is in line with the majority of data used in this research. When dealing with a 'scientific' phenomenon, externally gazing inwards and attempting to impose social theory results in the analysis viewing the material realm through a thick layer of epistemology.

Morton's final interrelated tenet of hyperobjects is referred to as interobjectivity, and it is intertwined with human intersubjectivity. The former alludes to the 'abyss' in front of things, the entity that emanates from objects to engender spacetime, and the latter is the shared space in which human meaning resonates. Morton (2013, 81-82) clarifies this relationship by arguing for a thinking of:

> ...intersubjectivity as a particular instance of interobjectivity with which humans are a feature. In other words, 'intersubjectivity' is really human interobjectivity with lines drawn around to exclude nonhumans.

This logic enables the binding of human action within the realms of nonhuman interests, cast under the consuming banner of interobjectivity, with intersubjectivity being the instances where only human actors are involved. Morton goes on to postulate the notion of a 'mesh'; this being the enmeshing of objects with one another in a series of links and gaps between the links. He argues that these links allow causality to flow between spatially distant entities.

The realm of interobjectivity, and the associated mesh that allows causality to flow between entities drawn into this type of relationship with a hyperobject, explains *how* action is engendered by a non-human. Due to their massive distribution, the various ways in which they manipulate time and their relationship with causality, it is not surprising to find that human action is a byproduct of the ontology of hyperobjects. Their very existence necessitates action through a host of different domains. This research has posed the question of how RBMK no4 has travelled, and the material actions accounted for throughout the empirical chapters provide examples of how its *agency* has produced them. Yet, this reassembling process does not provide a foolproof philosophical explanation. Granted, the agency of the nuclear non-human has powered the ANT methodological engine, guiding the analytical crosshair and tracing associations created by said agency, but it does not allude to the deeper philosophy of the situation.

Morton's notion of hyperobjects is hence a useful addition to this theoretical chapter, one that adds to the traditional ANT conceptual structure by unpacking the unusual philosophical nature of an entity that features prominently throughout this research. The hyperobject of RBMK no4's radioactive dispersion represents, arguably, the most 'visible' and, ultimately, impactful byproduct of the accident. It connected the remote site, and its nuclear non-human, to spaces across Europe, and cemented its place within the global economic, environmental, political and scientific consciousness for 30 years. Its distribution, agency, strangeness and, in some cases, dangers, engendered countless nodes of actions throughout European society (and beyond). It suggests the very literal answer to the central research question of how has Chernobyl travelled, as-well-as the philosophical backbone of the methodology that has sought to connect seemingly disparate human actions to an invisible entity that coated the landscapes of Europe and embedded itself within the biology of its citizens. For 30 years this invisible, unstable invader has forced citizens, governments and international institutions to think of the future, create actions tasked with mitigating the risk of the hyperobject in the present as a means of attempting to safeguard the future. It is the ever present entity that strengthens the featured associations and actions of this research, thus providing an ontological structure to the network in question.

2.5 Concluding remarks: two final conceptually guiding tools

This chapter has charted a path through philosophical debates and methodological practices, with the end result being a pragmatic meeting between aspects of Latourian and Beckian intellectual projects. 'Risk' permeates throughout this research. Each of the actions accounted for within the empirical core can be viewed as purposeful practices tasked with mitigating risk, on a variety of different levels, from the nuclear machines themselves (and how they were supposed to work) through to the explicit scientific and engineering debates around the risky nuclear industry. The byproduct of running Latour's version of ANT alongside Beck's risk society approach is a conceptual and methodological construct that seeks to counter certain blindspots of each approach, by means of the strengths of the other. The use of Morton's, more modern, notion of hyperobjects is further tasked with providing a philosophical explanation to the central research question; that is, philosophically reframing *how* the accident traveled, outside of the material transportation of radionuclides by means of the atmosphere.

Two final conceptual tools to be briefly deployed are Schatzki's (2002) concept of the *site* and Shaw's (2012) 'evental geography'. The central research questions asks how has Chernobyl traveled, and without a firm understanding of the material landscape of buildings and settlements that spawned the accident, any answer to this question would be incomplete. For Schatzki, the site is a *milieu* where its inhabitants, both human and non-humans, are congenitally subsumed within its creation, existence and logic. He goes on to articulate it as "the site specific to human coexistence: the context, or wider expanse of phenomena, in and as part of which humans coexist" (2002, 147). A Latourian reading of this definition places significance on the inhabitants, humans and nonhumans, within a site; their practices, relations and how the material setting facilitates and restricts said activities. Thus, the conceptual apparatus of the site resists any desire to specify a neatly bounded spatial entity and instead focuses upon its multiple inhabitants, assessing how these entities spark 'event relations'. These event relations have the potential spontaneously to produce newness, but it is the limits and restrictions embedded within a site that allow the concept to account for the "relatively stable objects and practices that continuously draw each other into relations and resurface social life" (Marston *et al*, 2005, 425).

In other words, paying attention to sites and their social life — 'social' across human/nonhuman divides — allows the researcher to detect the orders that influence and shape the practices of space present within any given site. This dimension is crucial to the envisioned intellectual project as it facilitates the 'touching down' of (as previously conceived) global, or meta-level, influences, rules and restrictions on the immediate, local, irreducibly material level. As an aside, it can be argued that Schatzki's concept of the site re-crafts older/traditional geographical ideas of 'the region'; but it is not the goal of this thesis to pursue intellectual genealogy, nor to rework histories of the discipline.

This attention to the materiality of the site is linked to its ontological limit, whereas how the site's inhabitants are congealed and composed essentially renders visible the site's internal logic. This matter is crucial as, according to Woodward *et al* (2010, 273), a map of a site can only be drawn according to its internal logic, "rather than [by] any generalizing laws". From this remark, we can clearly see the desire to differentiate this concept from the universalism inherent within meta-level theorising, thus furthering a picture of the site as a working materiality, always in a process of becoming, and only identifiable by the logic of its material composition. In other words, the concept of the site facilitates a materially attuned analytical description of a space, its human and non-human inhabitants, and the governing logic that ties the ontological melée together.

This logic is pertinent to the site of Chernobyl. As covered in the introductory chapter, the ethnographic account of encountering the Exclusion Zone prominently featured the Atomic City of Pripyat, a made-for-purpose settlement to house the nuclear power plant's workforce and families. Its inhabitants were housed, ordered and regimented by the material 'logic' of the nuclear non-humans, meaning the reactors installed at the Chernobyl NPP. These objects required thousands of human actors to operate them and, due to the remote placement of the facility, an entire city had to be built to accommodate these caretakers. Furthermore, the Duga 3 radar facility, the 'Russian Woodpecker', an awe-inspiring mass of metal and wiring, was placed near to the site of the Chernobyl NPP, due to its power requirements. Its thirst for electricity was so vast that it *had* to be constructed within a few kilometres of a juggernaut power source. These two examples suggest the site's internal logic as manifested through its material composition.

Power plant workers traveled from Pripyat to the reactor facility to carry out their professional duties, the children went to school every day at 8 am and returned at 2 pm, and neutrons diligently smashed into uranium atoms to produce heat to drive steam turbines. Until, one day, an eruption of 'newness' altered the site forever.

One further concept is hence useful in this regard, that of '*the event*', the eruption of difference-makings possibilities from within a site, here Chernobyl, to create newness (horrible newness for many) largely unforeseen. Shaw's notion of evental geography is focused around worlds, and their constitution pre and post a hugely disruptive event — the geoevent. There are similarities between Shaw's conceptualisation of worlds and Schatzki's site: namely, the importance played upon objects and their role within the material makeup of a world/site. For Shaw, there are two types of worlds, 'atonic' and tense', and the difference between them is based on their relationship to points and truths. For Shaw;

> Truths can be thought of as the process through which radical change is brought to the world. Badiou names a point the space of a decision or choice - when the truth procedure is tested, and indeed the very transcendental of a world is at stake. (2010, 401)

Thus, atonic worlds are totally devoid of truth, passive, controlled and free of points which tremble with the possibility of newness arising. Tense worlds, on the other hand, are filled with such points, constantly mounting a challenge against whatever forces, natural or social, that regulate and control. Within any given world, there are objects that exist and ones that are inexistent: ones that reject the normal parameters of what could and should be and happen in this world, and ones somehow bubbling under the surface, an excess awaiting what might be a catastrophic, world-changing release.The upshot is a delicate balance between the existent and the "infinite excess underlining the finite contours of a world" (Shaw 2010 618). Imperative to the approach of evental geography is hence the possibility of an inexistent object transgressing the barriers created by the 'policing' of any given world. If this rogue, inexistent entity commits such an act completely autonomously from this 'policing', its appearance into the world is referred to as an event-site, setting in train a whole series of event-relations that effectively flip that world into a whole new series of possible states (or indeed, worlds).

Within the Chernobyl example, prior to April 1986, the site was the site was in an 'atonic' (Shaw 2012) state: controlled, passive and policed. As a result of the explosion, a new orientation of spontaneous newness was instilled — 'tense' in philosophical classification. The use of Shaw's evental geography represents a conceptual augmentation tasked with philosophically accounting for the newness experienced within the site of the Chernobyl nuclear power station. The empirical chapters could be characterised as the international community's attempts to return the site into an 'atonic' state; regaining control and reinstating transcendental control. The explosions of 1986 fundamentally changed the site, but also created newness across a host of different spheres of society. The addition of Shaw's evental geography to this research's theoretical architecture equips the analysis with one final means of rendering visible the travels of RBMK no4. As the empirical analysis moves outwardly from the site, the materiality of the Zone, and the nuclear non-human is what is driving the accountable actions. These human actors were being directed by the new logic of the site, drawn into the nuclear non-humans expansive and dangerous network of unstable atoms.

Chapter 3

Slow moving neutrons, material moderators and a positive coefficient: a material take on the science and nuclear engineering network of RBMK no4.

For most people in the West, Chernobyl was simply an event - a catastrophic happening in an alien land populated by an intimidatingly confrontational ideological system. Its invisible materiality paid no homage to sovereign or territorial boundaries as the wind carried these human-made elements to spaces fraught with fears fuelled by geopolitical tensions surrounding the use of warheads of similar atomic nature. Chernobyl the event has amassed many guises over the last quarter century; it has become a story of Soviet technological inadequacies; a caricature of the perceived failings of the civil nuclear industry more generally; a spectrally mysterious location referred through the products of cinema and video games industries; and a space of forgotten wonderment to the groups of explorers who are intent on transgressing spaces that they are not supposed to access. In most iterations the event, and the space it inhabits through eternal radioactive ownership, have been awarded a form of common-sense status - an immortal reminder of the innate dangers of the nuclear age. These powerful mediated representations of Chernobyl have overtaken the material and discursive networks enrolled in and by the stricken station, subsequently rendering *invisible* the heterogeneous practices of the actors involved within the projects tasked with explaining, rectifying and safeguarding the object of unit 4. This inattention to the actions of RBMK no4's network of scientists, engineers and bureaucrats attracted to the nuclear non-human as a direct consequence of the event, represents a missed opportunity, a unique chance to account more fully for the lessons that the non-human actant of unit 4 has consistently taught the civil nuclear industry. Such an avenue of enquiry characterises the empirical chapters of this research, the quasi-clandestine actions of actors dancing to RBMK no4's new tune, the ontological answer to how the object travelled.

As covered in chapter 2, this research is utilising an ANT methodological framework and thus insists upon anchoring the analysis within the material realm, but epistemic constructs, the gathering and arranging of knowledge, invariably play a role due to the domains of enquiry pursued (and the importance of risk to the research). This chapter is tasked with rendering visible the central actant of this research, in all its material intricacies, but the documents containing the relevant data form epistemic constructs, in that they represent the finalised form of diverse scientific and engineering practices that sought to 'reassemble' the ontological form of the RBMK no4 and to identify how the event materially manifested itself within this particular object. ANT's *network* concept provides the means of bridging the gap between these two binary entities. Latour (1999, 17) states that his network "is the summing up of interactions through various kinds of devices, inscriptions, forms and formulae, into a very local, very practical, very tiny locus.". Therefore, the very process of performing an ANT analysis can provide an ontology to an epistemic structure, as it highlights the network that created it and keeps the object of analysis accessible.

It is not uncommon for scientific/engineering networks of knowledge practices to be subsumed into the background due mainly to the exclusionary barriers associated with the necessary levels of expertise needed to understand their complicated methods and discourses. However, this research has not conceptualised the event at the forefront of proceedings; its deployment at the outset has been utilised as a means of engendering the contrast between the epistemic construct of 'the event of Chernobyl' and the non-human ontology upon which the analytical magnifying glass has been directed. The material object which caused this unfortunate phenomenon, and the literal centre of the network in question, is of course unit 4 of the Chernobyl Nuclear Power Station. Thus, problematising the taken-for-granted mediations of the event are not of primary concern. Departing on a path of epistemological deconstruction would betray the tenets of the approach which provide this research with its arsenal. The route across the material plane that this chapter (and my research generally) will travel is altogether more technical, more scientific, more *ontological*. A destabilisation of the aforementioned mediations may be a byproduct of what follows, but it is not the intention.

Asking the question, 'how has the object of Chernobyl travelled?' allows this research to explore the vast constellation of actors who have been drawn into its network, with their actions being subsequently 'directed' by its agency. Crucially, the object itself must be taken seriously prior to accounting for the actions it spawned. Placing a non-human as the central actant within a research project requires careful legitimisation, which shall be achieved through a detailed exploration of both its ontology and the series of events that led to the two steam explosions of 26th of April 1986. Only then can this ANT account identify the agency of this nuclear non-human and thus begin the process of tracing the actions and associations it engendered and sustained, respectively.

3.1 The history and materiality of The Chernobyl Nuclear Power Station

The Chernobyl Nuclear Power Station (NPP), or V.I Lenin Nuclear Power Station as it was known in the Former Soviet Union (FSU), is situated in northern Ukraine, about fifty miles north of the capital Kiev. Construction of the station, and its atomic city of Pripyat, began in March 1970, with the initial ground works and a large scale civil engineering project tasked with creating the vast inland cooling reservoir initiated prior to the conclusion of the talks focused upon deciding which form of reactor was to be used there (Mould, 2000). Viktor Bryukhanov was the director of the Chernobyl installation and he proposed deploying Pressurised Water Reactors (PWR) at the site due to their inherently low reactivity design ethos and resulting manageable stability (Medvedev 1993). His view was contested by Anatoly Petrovich Alexandrov, a decorated Soviet physicist who was integral to the development and implementation of the High Power Channel-type Reactor (RBMK) across the Soviet Union. He was of the opinion that the RBMK was peerless in terms of safety and energy production (Belyaev *et al,* 1993); and, due to his stature, it was decided that four initial RBMK reactors were to be constructed at the Chernobyl site, each producing 1000mw when running at maximum power, with the prospect of two more to follow. In 1977, unit 1 began producing electricity for the Ukrainian national grid, followed by unit 2 in 1978. Units 3 and 4 were completed in 1981 and 1983 respectively, and the cumulative power output from these four reactors made the Chernobyl NPP one of the most powerful installations in the world at the time (Ahearne 1987). Two planned yet unfinished reactors reside in the eastern corner of the site; the structural carcass and internal machinery of unit 5 was in place, and the vast foundational works for unit 6 had been excavated by 1986. However, work was abandoned due to the events of April of that year. The V.I Lenin Nuclear Power Station was to be the pride of the Soviet Civil Nuclear Industry (Gale & Hauser 1988; Malko 2002), a six unit behemoth with the presumptive role of becoming their talismanic achievement, a monument to Soviet technical and engineering mastery of this most demanding of processes. The irony of what the word 'Chernobyl' now memorialises is plain to see.

Prior to delineating a timeline of the accident which occurred at Chernobyl's unit 4, a brief introduction to the nuclear reactors, with particular attention being paid to the RBMK, will be provided, since knowledge of this unique type of reactor is required in order to understand how the disaster manifested itself. Crucially, this descriptive process will begin to render visible the nature of the object's agency; that is, the identification of the material aspects of its design, construction and obscured *underlying* role which co-mingled to spawn the heterogenous technological and engineering network of influence across which it has subsequently travelled.

Several innate design 'deficiencies' and/or 'deviations' from the international (Western) knowledge practices of the nuclear industry are present within the RBMK, and these were fused with human operational irregularities. The result was the two steam explosions within the core of unit 4 (Yaroshinska 1995; Malko 2002; Salage & Milling 2006), and this complex nexus between the design of the nuclear non-human and the lack of proper care by its human operators has continuously influenced the actions of the international organisations tasked with ensuring the safety of all civil nuclear power stations in the immediate aftermath up until the present day. The descriptive passage below identifies the fundamental elements of this nexus, capturing the starting point for the journey across unit 4's attracted network.

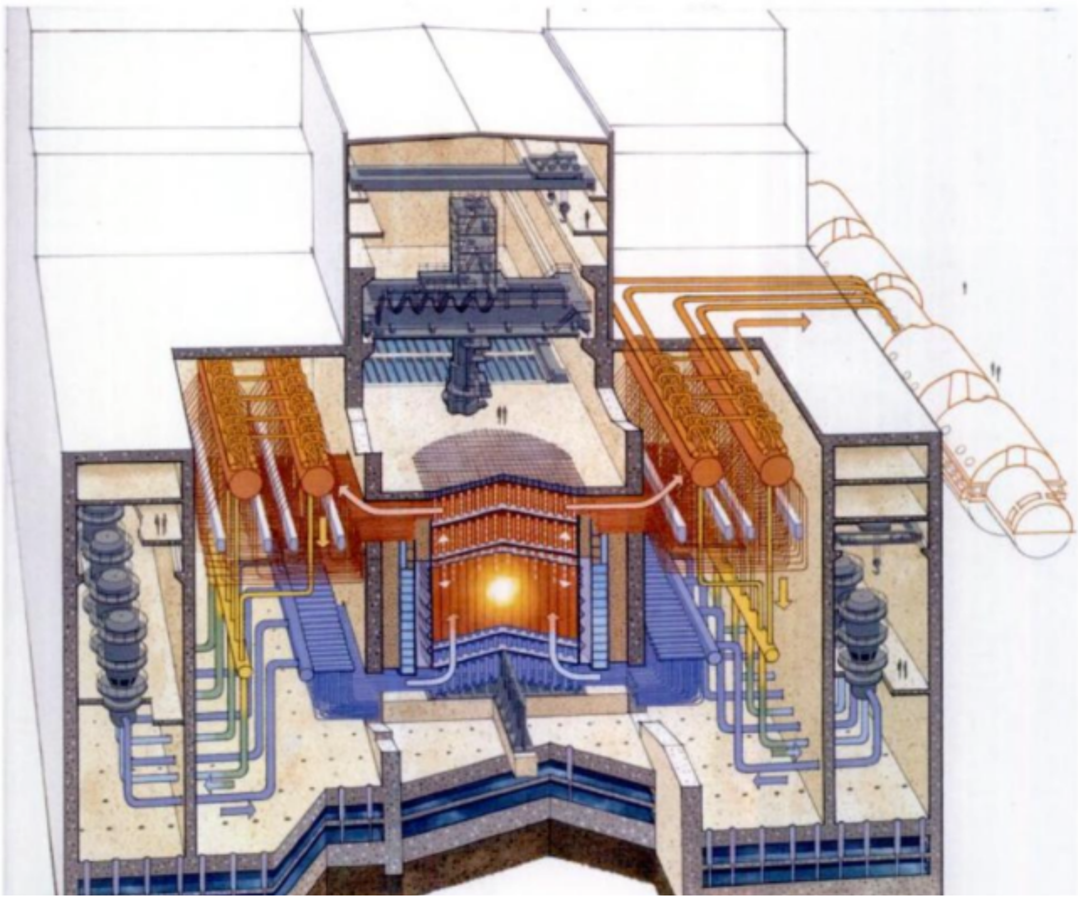

Figure 3.1: Graphical representation of the RBMK (Source: Mara 2010)

The RBMK was an *unusual* reactor design in comparison to its Western counterparts. It was one of two designs to come out of the Soviet nuclear industry during the 1970's (Josephson 1999), with the Water Water Energy Reactor (WWER) forming its nuclear brethren. The RBMK was a pressurised water cooled reactor, which utilised a huge array of individual fuel channels and featured a graphite moderator. This unique type of reactor fell under the meta grouping of light water graphite reactors (LWGR), and their widespread design, manufacture and implementation were almost exclusively a product of the Soviet Union. Only the British Magnox and advanced gas-cooled reactors (AGR) use graphite as a moderator within the civil industry (Medvedev, 1990), but they deploy super heated gas as a coolant, rather than light water. As an aside, the distinction between, and subsequent use, of light water (H20) and heavy water (D20) within a nuclear reactor has a notable impact upon design ethos. Chemically speaking, heavy water is an isotope of light water, as it has two deuterium atoms (as opposed to the two hydrogen atoms within light water); heavy water is 10% denser than its isotope cousin (Farhi *et al* 2015). If a reactor utilises light water within its design, then it must use another material as its moderator because light water is not efficient in absorbing neutrons. Conversely, heavy water is a much more efficient neutron absorbing agent, and thus can also act as a mediator (and coolant) (Pershagen and Bowen 2013). The importance of this process shall be covered below. Primarily, graphite moderated reactors are a product of the military industrial complex which contributes to the plutonium production economy. Therefore, the fundamental distinguishing factor within the design of the RBMK, that which makes it unique within the civil industry, is the use of graphite as a moderator.

Before a detailed summation of how the object of the RBMK produces electricity is provided, it is imperative to appreciate the importance of a moderator within any nuclear reactor: why it is needed, and why the use of graphite was so unusual. As with most aspects of the atomic age, it begins and ends with uranium. Within uranium dioxide there are two primary isotopes, U-235 and U-238, and the latter statistically dominates the natural element in terms of the collective mass (Wallner *et al* 2014). The process of nuclear fission takes place within U-235 atoms and the chain reaction later spreads to the plentiful U-238atoms. A useful analogy to help visualise this operation can be found in the lighting of a traditional wood burning fire, be it in an open pit or a log burning stove. Without the use of hexamine fuel tablets, or 'firelighters', the fire may struggle, or simply not be able to achieve criticality; that is, it will not reach the temperatures required to ignite the natural wood fuel. Thus, in terms of the collective mass of the total fuel which the fire has to consume, the hexamine represents only a tiny percentage, but its importance to the initial reaction and subsequent inferno cannot be understated. This is the role of U-235: it is the atomic firelighter. This presents an unavoidable mechanical issue for any nuclear reactor. Due to the dominant percentage of U-238 over U-235 within uranium dioxide, a specialised system is required to spark the initial reaction within the subordinate isotope, which is achieved through the use of a moderator. In essence, a moderator slows down fast moving neutrons to the speed which destabilises U-235 atoms, subsequently prompting them to embark on their violent and atomically disruptive journey towards a self-sustaining reaction within the meta structure of the uranium fuel (Glasstone and Sesonske 2012). The ideal moderator for a fission reactor should be roughly the same mass as the neutrons involved within the process, and hydrogen is the ideal element (Wagemans 1991). Thus, water represents one of the optimum moderators due to its atomic similarities with the neutrons involved in nuclear fission and, fortuitously, its innate cooling properties. The only issue with the use of water as a moderator is the fact that it is also acts as a neutron absorber, so it not only slows neutrons but also filters them away from the uranium dioxide fuel as it naturally consumes them.

This slowing is counter-balanced through the enrichment of uranium, which specifically means increasing the percentage of U-235. The enrichment process requires a heterogeneous infrastructural network specifically tasked with re-orientating the internal isotopic balance within the uranium dioxide fuel (Berkemeier *et al* 2014), an expensive and time-consuming operation, one which represents a barrier on the road to the proliferation of weapons grade uranium. In other words, any state which uses a light water moderated reactor must have domestic, or internationally agreed upon, access to enrichment capabilities (Brown and Kaplow 2014). During the 1970's and early 1980's, enriched uranium was at a premium. This period of course played host to the tenacious nuclear arms race between the United States and the Soviet Union. Crucially, the keystone components needed in the construction of a nuclear missile and a nuclear power station are identical: enriched uranium and/or plutonium. Thus, the Soviet civil nuclear industry chose a design ethos for both of its flagship reactors of the era which shied away from the use of fully enriched uranium in a bid to ease the bottleneck between civilian and military demand. Hence, instead of water, the choice was graphite, a choice ultimately mired in Cold War logistics.

The RBMK used slightly enriched uranium dioxide fuel at a ratio of 2% U-235 to 98% U-238, rather than the conventional 5% U-235 concentrations traditionally deployed within Western reactor design (IAEA 1999). Thus, only a partial enrichment process was required to meet the demand for fuel from the Soviet fleet of reactors, subsequently freeing up the more highly enriched product for military use. As previously mentioned, the RBMK used graphite as a constant moderator and light water as its primary coolant. Therefore, the need for 5% enriched uranium dioxide fuel was negated through graphite's lack of intense neutron absorbency. In theory, the compositional make up of this type of moderator has plentiful advantages, none more theoretically beneficial than a permanent means of igniting the fission reaction within the valuable 2% (Pershagen and Bowen 2013). Regardless of these supposed benefits, the use of graphite as a moderator was shown to be innately dangerous through the post-mortem of the Chernobyl accident, to be covered in a specific section below. For now, we have gained an understanding of the importance of a moderator within nuclear engineering, and attention will now move to the inner workings of the non-human hybrid of the RBMK.

The RBMK is a product of its era, an example of 1950's technology and 1970's engineering (Medvedev 1990; Malko 2002; Salge & Milling 2006) which in 1986 was obsolete in both fields. This criticism could be levelled at most older generation nuclear reactors, regardless of their origin; but, unlike a mobile phone or a laptop, they cannot simply be traded in for the new model due to the phenomenal cost of their construction and infrastructural importance. The means through which the reactor produces electricity forms the bedrock on which its obsoleteness is fastened. The reactor's core is constructed from closely packed graphite blocks; these in turn form vertical columns about 10 metres in height - there are 2,488 graphite columns in a RBMK-1000, with a collective mass of over 1,700 (Aden *et* al 1977; Emel'yanov *et al* 1980; Medvedev 1990). This array of graphite stacks forms the material structure of the core as-well-as the moderator, in essence tasking it with moderation and physical assemblage. The fuel channels are formed by the material arrangement of the graphite moderator which subsequently engenders 1,622 channels within the second generation RBMK present at the Chernobyl facility. As a brief aside, there are material differences between the first, second and third generations of RBMK, but this is not the place to detail the minute elements of difference. The meta-structure and design philosophy bridge every generational divide, with the size and support system forming the primary source of evolution (IAEA 1999).

The aforementioned fuel channels house the uranium dioxide fuel, which is compressed into small cylindrical pellets and stacked to fill the ten metre vertical void in between the graphite stacks. This is not an airtight fit as each fuel channel must also house the primary coolant system. This results in a distinctly complex design of reactor, one split up into over 1,000 microcosmic cores each with its own levels of reactivity, coolant and steam generation systems. In other words, the structure is akin to a beehive when viewed from a position of verticality. Figure 3.2, taken during the research trip to the Chernobyl facility, is of the control room of unit 4, and it depicts the structure of the core. On the wall is the core's primary monitoring system where each of the channels can be viewed, and this system was identical for unit 4. Each individual honeycomb within the meta structure of the hive is autonomous in terms of physical separation from its neighbours and its individual role of producing honey, but it feeds intrinsically into the interconnected governing function of the hive. Thus, the core of the RBMK shares visual similarities with the abode of the honey bee, as-well-as metaphorical connections to a hive's division of physical responsibilities across its structure.

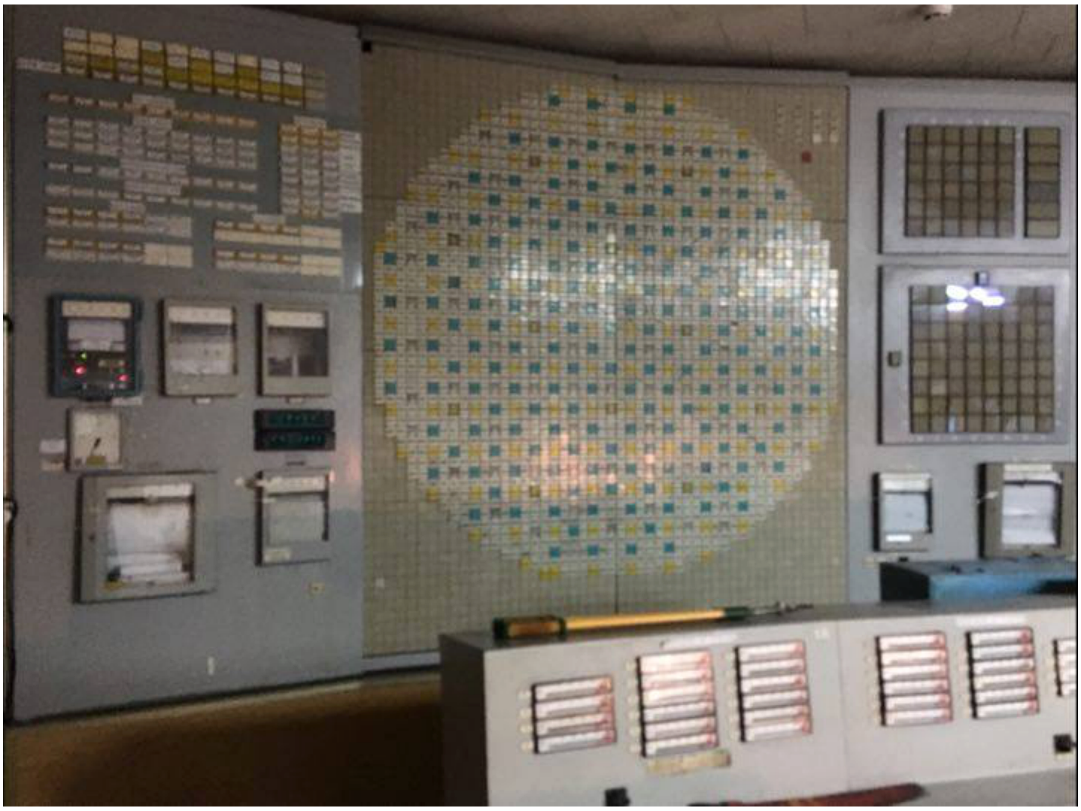

Figure 3.2: control panels of unit 1 (source: researcher's own photograph 2015)

Control of the reactivity is fundamental to any nuclear technology, and the RBMK utilises 211 control rods to achieve this most imperative of operations (Salge and Milling 2006). These neutron-absorbing rods have their own channels within the graphite core and their actions are akin, allegorically, to a magnet. They are assembled using boron carbide due to its ability to absorb neutrons, subsequently preventing the generation of new neutrons, depending on their levels of insertion into the core, which in turn moderates the chain reaction (Chan and Dastur 1989). Hence, they attract neutrons in a manner similar to how a magnet attracts ferromagnetic materials. Each rod can be remotely inserted independently from the control room and it is the duty of the reactor's operators to perform a delicate balancing act, carefully inserting and retracting the plethora of control rods at different locations to ensure that the landscape of the core performs at optimal levels. Simply put, the further the rods are taken out of the core, the higher the reactivity. Thus, the chain reaction is inhibited when they are inserted. When detailing the obsolete aspects of the RBMK, the control rods take centre stage. The official rate at which they could travel into the core was 40 centimetres per second (Medvedev 1990; Josephson 1999; IAEA 1999; Malko 2002), and so, for the entire assembly to travel the 10 metre length of the core, it would take 20 seconds. In the late-1980's this was a totally unacceptable safety practice (INSAG 1996), and by contemporary standards it is unthinkable. One of the most frightening aspects of a nuclear reactor, regardless of its design and/or origin, is the rate at which it can heat up to a point where the system cannot cope. The description up until this point has delineated an array of individual mini reactors within the RBMK's core, each with its own permanent moderator and fuel assembly. Thus, if their delicate ecosystem is not dutifully managed, the potential for this type of system to heat up exponentially is massive. In hindsight, the RBMK should have been equipped with a control rod system which could have been fully inserted in a few seconds, not a quarter of a minute. The events of April 1986 highlighted this deficiency in explosive detail.

So far we know that the core of the RBMK is primarily constructed of graphite, with a heterogeneous array of independent fuel channels, and an inadequate control rod system with its own designated openings within the graphite block. Thoughts will now turn to the unique ways in which its cooling system and steam generation procedures are intertwined - it should be noted that this generalised topic addresses several of the mechanical/material factors which contributed to the accident. Outwith the renewable industry, a power station can be simplified as a means of engendering and sustaining a heat source for the purpose of boiling water to create steam, which in turn drives mammoth turbines. As mentioned in chapter 1, this has always been the case with commercial electrical production units; even as the scientific collective strives towards the commercialisation of nuclear fusion, the most ambitious and celestially inspired creation of heat - that is, the process that eternally powers the stars of the universe, this fundamental practice of steam generation to spin turbines - will remain. Typically in Western reactors of the era, and especially contemporary examples, there are two circuits for water; one tasked with cooling the fuel, and one for generating steam (Scott 2007). This design principle necessitates a heat exchange system as it is believed to be good practice to separate the radioactive coolant from the water which will eventually drive the steam turbines (Ahearne 1987; Chernousenko 1991). This arrangement reduces the amount of physical appendages required (ie. pressurised pipes, welds, and so on), subsequently limiting the total area through which the radioactive water has to travel. The RBMK did not adhere to this practice, and instead it was constructed with individual cooling circuits for each fuel channel which were fed from one meta-water circulation system (INSAG 1996). This resulted in a dizzyingly complicated plethora of pipes, valves, connectors and gauges - in other words, an intense interconnected network of appendages which needed to be fully pressurised and operational for the reactor to function as intended.

Furthermore, the immense temperatures and pressures involved within the controlled process of nuclear fission are difficult to fathom. Almost every aspect of the system produces statistical averages delineating an object which continuously tests and stresses its engineering and technological framework: a wild creature paradoxically tamed through the material cage to which it owes its existence. This is evident in the routine 'stress testing' (a form of risk calculation) performed on all types of nuclear reactors worldwide. Within the RBMK the graphite columns reached 700 degrees celsius during normal operations (Medvedev 1990), and the pressured coolant water's normative temperature was 170 celsius at 8.2 megapascal (Malko 2002). These figures portray a hostile environment, one which could potentially be mitigated through the separation and individualisation of crucial systems which would ease pressures and tensions placed upon them. However, as mentioned above, an important feature of the RBMK reactor was the marriage of the coolant and steam generation water circuits, meaning that the highly pressurised water cooling the fuel was in turn evaporated and fed into the turbine generators in a continuous circuit. This design decision, coupled with the permanent graphite moderator, resulted in the RBMK having an extremely large positive void coefficient (Afanasieva *et al* 1993), and, prior to the elaboration of this technical term, it should be stated that this state can be extremely dangerous. The void coefficient is a measurement of how any given reactor responds to increased steam formation within the water coolant. The difference between a positive and a negative void coefficient is connected to a reactor's relationship with water, and the role it plays within its fission process. If a unit which has been designed to use water as moderator *and* coolant, the increase of steam bubbles within its core will decrease the water's ability to slow down neutrons (Seiler *et al* 1988). In other words, an unexpected rise in the temperature of the coolant water to a level with which the material confines of the core are not 'comfortable' results in the above-mentioned increase in bubbles, which in turn slows the fission chain reaction due to the water's new inability to act as a moderator. This dynamic is referred to as a negative coefficient, and it is fundamentally appealing due to the innate controllability of any reactor designed in conjunction with this line of physics.

Even in the era of the RBMK's design inception, most nuclear reactors were built with an innate negative coefficient (INSAG 1996). Even without the use of the all-seeing eye of hindsight, it appears misguided to have green-lit a design that did not adhere to this knowledge - especially when considering the principles associated with a positive coefficient. As mentioned, the permanent graphite moderator within the RBMK plays a telling role due to its physical moderating properties. If the temperatures of the coolant water rise, and an excess of steam bubbles begins to appear, the water loses its ability to act as a *coolant*, its primary purpose with this type of reactor. This is extremely bad for the controllability of the reactor as, without the habitual circulation of water of the correct temperature, the fission reaction will relentlessly increase in temperature due to the material presence of its graphite moderator. In other words, even with the increase in steam bubbles and consequent rise in coolant temperatures, the neutrons are still slowed by the graphite. Furthermore, although graphite is the primary moderator within the RBMK, its coolant water still inadvertently acts as one too, due to its innate neutron absorbing qualities. Thus, when this vital pool of liquid coolant begins to vaporise, it relinquishes its natural absorbent characteristics, once again contributing towards the positive coefficient rate. During this disastrous process, the reactor's first line of defence against an accident literally evaporates.

The International Nuclear Safety Advisory Group (INSAG) was one of several international groups who conducted research upon the accident at unit 4 in a bid to determine what went wrong, and, more importantly, how to secure the future safe running of the remaining fleet of RBMKs across the FSU. The report produced by the INSAG stated that the positive coefficient of the reactor, which was only identified in the post-disaster era, and the inefficiency of its control were the key material aspects of the reactor's construction which contributed towards the explosion (INSAG 1992). Taking into consideration the RBMK's unique singular water circulation circuit and all that has been discussed regarding its boisterous reactivity levels, the imperative to keep its watery life blood at the correct temperature became 'chillingly' apparent.

Coolant systems within any nuclear reactor are of immeasurable importance, even within reactors which operate with a negative coefficient (Glasstone and Sesonske 2012). The constant circulation of vital water represents the first line of defence against the exponential rise in heat witnessed during uncooled fission products. This perpetual circulating of coolant liquid keeps the fuel within the operational temperatures that the object is designed to withstand. Without this steady flow, the fuel will rapidly heat up to a point where it will begin to melt its structural containment. In other words, this will cause a literal meltdown - the ultimate accident which could befall a nuclear facility. Therefore, due to its singular design ethos, the water circulation system within the RBMK was actually tasked with *three* integral roles: steam generation, fuel coolant, and the material first line of its safety systems. The RBMK featured an emergency core cooling system (ECCS) which was partially autonomous from the primary water circuit (IAEA 1999), and its role was to activate if the control systems gauged that the core was getting too hot. Every format of peer stations has a system akin to this; and, due to its essential role in the occurrence of an emergency, its electricity requirements are primarily met by the station output *as-well-as* by backup generators (D'Auria *et al* 2005). It is standard practice for any power station to run its fundamental systems from the electricity it produces, which is especially relevant to nuclear installations. The necessity for these non-humans to be 'self-sustaining' reveals itself when thoughts turn towards its safety systems, be it the control rod governing systems, or the water circulation machinery. An innate safety precaution is hence the use of backup diesel generators which are capable of supplying its essential systems with the necessary power to function during an electricity blackout, thus completing their 'self-sustaining' ability. However, these backup diesel generators cannot guarantee an instantaneous switchover and full supply of power - there will always be a delay. How to mitigate this delay is of primary concern for any plant's operators, particularly those tasked with caring for reactors of a similar design to the RBMK with its slow control rods' insertion rate. As an aside, this relationship between the RBMK's backup generators and the rate at which they can sustain the essential control systems will be covered below. For now, we must strive to understand further the subjective nexus between an efficient design ethos and a safe operational dynamic.

Efficiency is a crucial aspect of any industrial object, and the RBMK's singular water circulation system could be viewed as an efficient practice. Nuclear reactors do not form an exception to this rule, but their drive towards an efficient operating standard must be held to higher levels of accountability and innate safety standards than their non-atomic counterparts, due to the *unwieldy* nature of the beast. There are plentiful ways to increase the efficiency of these non-humans, but they are implemented at the expense of the reactor's intrinsic safety levels - the Chernobyl disaster illustrated that engineering efficiency should always be of secondary concern to securing a flawless operating procedure. In essence, the water and steam system within the RBMK can be simplified and visualised as a circular loop (as illustrated in figure 3.1 at the outset of this section), one which encompasses the complex fuel channel network within the graphite stacks and the steam powered generators. However, each RBMK-1000 has two 500MWe turbine generators on each side of the core (Sorokin *et al* 2006), and its physical landscape of over one thousand fuel channels was segregated into two distinct sections which fed their respective electricity producing appendages. This design decision subsequently split the territorial responsibilities of the primary water circuit in two, and, crucially, allowed the reactor to be partially shut down while the other half remained active (Tyapkov *et al* 2011).

This partitioning of the core and the resulting ability of the RBMK to be refuelled while still producing electricity, albeit at half power, was another major departure from conventional nuclear reactor design. The material structure of a Pressurised Water Reactors (PWR) centres around one large, steel, pressurised vessel, which houses every fuel rod and is tasked with separating the coolant water from the steam generation system by means of the aforementioned heat exchange mechanism. Think of this system design as a titanic spherical container, hermetically sealing/grouping the uranium fuel within its ten inch steel outer shell, and contrast this image with the aforementioned 'beehive' RBMK analogy. Both of these systems have their pros and cons: the PWR system being fundamentally more controllable, yet necessitating a period of full shutdown every six to seven years for refuelling (an infrastructural dilemma for any nation state's national grid); while the RBMK design allowed for refuelling/repairs during half power operations, but also entailed a dangerously complex object which lacked full containment. In other words, we return to the aforementioned binary between efficiency and safety, with both meta-designs providing excellent 'centre right' and 'centre left' examples. As stated at the outset of this passage, the RBMK was principally designed around the generation of electricity *as-well-as* the production of plutonium. Plutonium is a human-made, transuranium element, synthesised through the conversion of U-238 into PU-239 by means of neutron bombardment during the fission process (WNA, 2012). In other words, it represents the transformation of the previously non-fissionable dominant isotope of uranium into a much more potent alternative.

When this mutation takes place within the core of the RBMK, or any uranium powered nuclear reactor, it generates a huge amount of heat. Any 'uranium fuelled' reactor is actually partially powered by the plutonium that it inevitably produces when the neutrons from the U-235 chain reaction spread to the U-238. It should be noted that this is just a vastly irradiated byproduct of the process; the primary use of plutonium is within thermonuclear warheads. In any Western nuclear state, there is a separation between the military production of plutonium and the civil electricity producing industry. Typically, a branch of the military industrial complex will operate nuclear reactors with the sole purpose of creating plutonium - due to the risk of weapons proliferation, this process is exclusively conducted by the apparatus of the state. There are fundamental differences between 'weapons-grade' and 'reactor-grade' plutonium, and these revolve around how long the uranium has been kept in the nuclear oven. The reason that fission elements emit heat is a result of their atomic decay; as they are bombarded with neutrons, their compositional atomic structure is destabilised, which releases atoms within the element. Weapons-grade plutonium is produced by irradiating uranium for three months in a purpose built unit, and reactor-grade plutonium is irradiated, or 'burned', for a minimum of three years within a system akin to the RBMK (Hamblin *et al 1998)*. Thus, the former is a much more potent example of the 'breed', purposefully removed as soon as it has transmutated from U-238, while the latter is a byproduct of a system which, due to its infrastructural importance to the national grid, cannot be shut off to retrieve this 'precious' cargo (WNA, 2012). This indeed is the Western logic behind the production of plutonium, particularly regarding the form that is used within Western iterations of three stage thermonuclear weapons - quality and safety being achieved through a concept of separation of production networks, regarded as more important than the streamlining of manufacturing efficiency and pushing for increased quantity of the final product. It should be apparent at this juncture that the Soviet system did not adhere to this practice, and the RBMK is a non-human monument to this lack of adherence. All that has been described thus far cumulatively results in a nuclear reactor design which produced and facilitated the neat and efficient removal of readily transportable plutonium during online functions. The subversive purpose of this intentional design ethos can only be speculated upon, and it is safe to assume that Gorbachev's policy of 'Glasnost', with its arguable veil of subterfuge and hypocrisy, would not extend to providing details of the nexus between the Soviet military machine and the widespread implementation of their flagship reactors.

The militaristic importance of the Chernobyl facility is further brought to light by means of the Duga 3 radar facility (figure 3.3).

Figure 3.3: Panoramic shot of Duga 3 radar facility from the roof of the control building (source: researcher's own photograph 2015)

This towering mass of wires and steel, affectionally nicknamed as 'The Russian Woodpecker', due to the distinctive 'pecking' noise that it made through radio waves, was the Russians' primary radar complex on their 'Western front'. The facility was shrouded in secrecy, with some claiming that it was *the* most secretive project of the Soviet Union during the Cold War (Evstratov *et al* 1994). It is situated roughly 5kms away from the Chernobyl facility, and has a power line directly to it from the Station. It is estimated that it consumed over a third of the power plant's total output, and its placement alludes to the militaristic nature of the entire site.

3.2 The material pre-context of the accident

As the essential parameters of the RBMK's design have been described, attention will now turn to the sequence of events that resulted in the accident. This will be accompanied by one final technical exposition on the relationship between the passing of time and the controllability of a nuclear reactor, which will provide an excellent segue into the timeline of events which resulted in the explosion at unit 4 in April 1986. Once again, we return to the uniquely divergent characteristics of uranium. In a bid to illustrate what is being discussed, another comparison between easily recognisable, conventional electricity generating stations and their nuclear alternatives will be deployed. This comparative exercise begins with the recognition that coal, oil and natural gas power stations are extremely hungry non-humans. The rate at which their eternal furnaces consume hydrocarbons is both environmentally shocking and logistically impressive. This is due to the instantaneous and carnivorous nature involved during their production of heat - ignite a bucket of oil and it will rapidly devour itself until the total depletion of its mass through a simple chain reaction. Thus, there is a transformation happening within the 'core', or furnace, of traditional formats of power station, one which combusts the fuel, subsequently transforming it into a gas which leaves the body of the object. In other words, the mass of the fuel is transported within the process, and the station itself is merely a means of conducting this action on a large and continuous scale. Therefore, the non-human itself never changes, it acts as a conduit through which solid hydrocarbons are combusted into gaseous entities. On the other hand, nuclear power stations do not require continuous nourishment in order to sustain their heat source. Once their cores are filled with uranium dioxide, they have the ability to run without refuelling for several years, and the continuous chain reaction will only increase in intensity as time passes.

On paper, this seems like an advantageous aspect of splitting the atom, and when viewed in isolation it is. However, unlike their traditional counterparts, the fuel does not migrate from the nuclear reactor during a cycle - its mass, for obvious reasons, is imprisoned within the confines of the core. Furthermore, during the process of nuclear fission, the radionuclides within the fuel mutate into more volatile examples (eg. the aforementioned transformation of U-238 into PU-239), resulting in an evolving landscape within the non-human of the reactor. Thus, when compared to the above-mentioned traditional power stations, a nuclear example is not a conduit for the transportation of the mass of its fuel, but rather an oven which 'bakes' its ingredients, subsequently producing a new, capricious mixture of precarious elements. Hence, there is a direct relationship between the exponential increase of volatile radioactive isotopes within the fuel and the length of time between refuelling of the reactor. As time passes, the controllability of the object of the reactor decreases as the radioactivity and innate temperatures rise, particularly within complex designs like the RBMK. When viewed with an impossible lens of objectivity, one would suggest that refuelling should take place at the point when operational safety is negatively impacted by the increasing volatility of the fission material encased within the core of the object. However, as previously indicated, refuelling a reactor results in it being taken offline (or running at 50% capacity in the case of the RBMK) for a sustained length of time, which will have massive ramifications on any country's national grid, regardless of its economic and infrastructural development. Therefore, monetary interests inevitably play an influential role within a dynamic which, due to the potential dangers involved, should be governed purely by a perfectionist drive for safety. This nexus could provide endlessly interesting avenues of research across the global nuclear landscape, but, for the purpose of this piece, it must be recognised that unit 4 of the Chernobyl nuclear power station had been running its one and only fuel cycle for three years and four months (Medvedev, 1990, Mould 2000) since its 'official' date of launch on the 20th December 1983. This period, for all intents and purposes, brought the fuel to the end of its life cycle. Thus, on the 25th April, 1986, the non-human of unit 4 was in an extremely volatile state.

This technical proviso neatly summarises the inherent conditions of the non-human of unit 4, and provides a means of understanding why its material state at the time of the accident was, in effect, so *difficult* to control. The purpose of detailing this consideration is to contextualise the material landscape integral to the sequence of events which resulted in the explosion within unit 4. This process, combined with all that has gone before, begins to renders visible the appendages of the object's agency. Once the accident itself has been explained, the task will be to correlate the technical, mechanical and physics based phenomena which form the backbone of Chernobyl's 'scientific' network, subsequently allowing the mapping of the trajectories travelled.

3.3 The road to meltdown

The explosion within the core of unit 4 of the Chernobyl installation was a combination of the aforementioned physical complexities of the object's design and, with the benefit of hindsight, illogical human decisions. As the material construct of the object has been laid out in (hopefully) readily understandable terms, the operational irregularities will now be covered as these culminated in the catalyst which brought the station to its explosive demise. The Soviet decision to award the fallible human element a massive amount of responsibility when designing the reactor safety protocols (rather than allocating these hugely important tasks to an autonomous machine) will be covered in a later section. What shall be referred to as 'the test' from this point on will now take centre stage. To recap, all that has been described thus far has provided a material situational backdrop; it has delineated the RBMK in a rather negative light, one illuminating the physical aspects of its design that, when added to the evental happenings during the test, resulted in the explosion in April 1986.

The test — a specific procedure planned and enacted at the Chernobyl facility in April 1986 — represents the point in space and time where the innate design deficiencies of the RBMK co-mingled with its ageing fuel load, and also with a questionable evaluation procedure tasked with exploring the nexus between the backup diesel generators and the time it took for them to power the station during a loss of electricity situation. This evaluation was initiated due to the perceived unacceptable risk incurred by the delay between the starting of the three back up diesel generators and the sixty seconds needed for them to reach the 5.5Mw output required to run the main water circulation system (Shcherbak 1989; Medvedev 1990; Chernousenko 1991; IAEA 1999; Mould 2000; Malko 2002; Salge & Milling 2006 etc). The station's operators believed that they could mitigate this delay by utilising the residual energy within the steam turbine generators as a means of bridging the minute gap needed for the backup generators to reach full power. As a brief aside, consensus has been reached regarding the reasoning behind the creation and subsequent implementation of the test, but several contrasting arguments arise surrounding the historical frequency of the test. But the minute details of the logistical running of the station were not made public - several accounts from the years that followed work on the basis that there were at most two tests conducted before 1986 (Medvedev 1990), and others do not mention the existence of earlier tests when giving their descriptions of the test and the accident (Mould 2000, Malko 2002). This is in contrast to the Nuclear Energy Institute [NEI] (2011) and the Chernobyl Gallery's (2005) accounts of the historical frequency of the test procedure, both claiming that the station's operators had sought to take advantage of the potential of the residual energy within the turbo generators on three occasions prior to the fateful day in 1986. Regardless of this lack of consensus about the historical prevalence of the test, its activation at the end of the object's fuel cycle was of telling importance and suggested operational incompetence.

What follows is a condensed description of the parameters of the test itself, the material environment within the core which was stimulated in order to conduct it, moving on to a concise timeline of the disaster itself: discursive structure, material practice, and translative explosion. The 25th April 1986 saw the first planned maintenance and refuelling period for unit 4 at

Chernobyl, and the test was arranged to be conducted just before the shutdown was initiated – this pragmatic programme, on paper, represents an efficient means of completing both necessary acts in one sitting. In order artificially to create the conditions required for the test to be situationally valid, the power level of the object of unit 4 had to be lowered from 1000Mw to 700Mw (Mould 2000). This was no easy feat for a complex unit like the RBMK, with its vast independent landscape of microcosmic fuel channels and an internal fuel load at the end of its life cycle. The test procedure also stated that, once these levels were reached, one of its three turbine generators was to remain running at full speed; and when these dual environmental conditions were met, the steam supply was to be shut off and the generator's residual performance was to be recorded as a means of determining if it would produce enough energy to bridge the aforementioned gap. Finally, once these readings had been taken and the emergency generators had reached maximum capacity, the turbine generator would have been allowed to freewheel down to a standstill.

The following timeline has been taken from the INSAG (1992) official report on the disaster. This decision was made due to the fact that this international organisation attained the information upon which it based its findings from first-hand data. There are numerous timelines provided throughout the discourse focused upon the accident itself, many of which are analytically superior to the sterile INSAG report. For example, Mould (2000) expertly highlights the several stages of failure, both technical and operational, subsequently detailing the external influences which co-mingled with the mechanics of the object; whereas Medvedev (1990) takes an altogether more critical stance when attempting to piece together the strange happenings within a bureaucratic network surrounding the Soviet Civil Nuclear Establishment during the period of the test. Malko (2002) approaches the topic with the clinical mindset of an engineer, depicting the *nuts-and-bolts* of the unit's systems with steely efficiency and explaining the sequence of events during the test with unflinching technical jargon; and finally Shcherbak (1989) provides a first person perspective of the event itself, produced through *first hand sources* attained from eyewitnesses and station employees. This is in no way a comprehensive listing of all the delineations of the test and its awful failures, but it does provide a flavour of the different varieties available: that is, the heterogenous mix of representations surrounding a mechanical phenomenon. Due to the quasi-scientific nature of my own piece of research, the decision to utilise the document which features the highest levels of objectivity was made in a bid to ground the analysis firmly within the realm of the object of unit 4, rather than being subconsciously led by the subjectivities of the actors responsible for other pieces of literature. Thus, taking these negotiations into consideration, the INSAG report was chosen as my prime source.

3.4 The Test

The period which preceded the test itself featured a bureaucratic cluster of confusion that perhaps only the Soviet Union could produce. Initially, the test was to take place during the afternoon of 25th April as the scheduled date and time of the planned maintenance period, and in keeping with this rhetoric unit 4 began its slow descent from maximum power down to the required 700 megawatt (Mw) at 14:00. It was at this point that the Emergency Core Cooling System (ECCS) was manually disengaged for two reasons: firstly, it would automatically have stepped in as it was designed to when the reactor reached these lower power levels; and secondly, the test was tasked with creating a situation where the electricity supply to the ECCS would have been cut off, and the only way authentically to recreate the desired situation was to turn it off. Just before the test was about to be fully initiated, the station received a call from the controller of the Kiev electricity grid requesting that the shutdown of unit 4 be postponed till 23:10 that night (this information was not provided within the INSAG report, which only provides the actual timescale without explanation of the delay: thus, this insert is subject to a reference from Mould 2000). This eleven hour delay meant that the reactor was kept at this lower power level and the object and its operators subsequently found themselves in an unusual equilibrium. Unbelievably, the ECCS was not reactivated during this extended window, which represented a direct violation of the station's operating protocols. During the period between 23:10 and 00:30, the reactor's standard control rods (referred to as local automatic control rods [LACs]) were removed from their graphite housings within the core, and the secondary rod system (known as automatic control rods [ACs]) were switched in their place. At this juncture, the operators in charge of the test and the object itself neglected to reset the inertia starting point for the ACs; in essence, they forgot to programme them to the unique requirements of the test, and the reactor's power level plummeted to only 30Mw. This, for obviously statistical reasons, was far below the required levels of 700Mw needed to validate the test itself.

As stated at the outset of this section, unit 4 was in a volatile state when this experiment was being conducted - the last thing it, and its operators, wanted to be doing was intensely increasing and decreasing the reactor's power output with purposefully artificial frequency. The standard natural progression of events post ACs' insertion to the levels witnessed at **00:30** was full shutdown with the intention of terminating the fuel cycle. However, this would obviously have ended any possibility of the test being conducted and a hierarchical backlash would have befallen the object's seemingly absent minded operators and the station's director. Fearing this outcome, the operators embarked upon the precarious stabilising mission of withdrawing the ACs enough to sustain the chain reaction as it was almost extinguished and also to increase the total power output back to 700Mw (over two hundred times the capacity at which it was then set to run). This task was made difficult by the appearance of xenon gas which accumulates during the natural shutdown procedure. By **01:19** the operators managed to stabilise the power output at 200Mw and the eight pumps which fed the coolant water across the two sides of the core were still running at maximum efficiency. This created a unique situation within the body of the reactor; fractional power output in tandem with maximum coolant flow rate, which in turn led to a steady fall in the steam production within the singular water circuit. This situation resulted in a sizeable decrease in pressure within the steam drums which fed the turbine generators. At this point the operators attempted manually to rectify this lack of pressure and water level within these drums by deploying the secondary feed water pumps. It should be noted that this situation, under regular operating procedures, would have been automatically avoided by the reactor's steam level protection system due to its preprogrammed task of overriding any manual inputs and tripped (kill the chain reaction through full and terminal insertion of fail safe control rods) the reactor due to the dangerously low pressures within the steam drums. However, akin to the disconnection of the ECCS, this system had been disengaged in order for the test to be carried out without the object's protective systems stepping in and eradicating the potentially dangerous core environmental conditions.

At this juncture, the preparations for the test were running the reactor in a perilous state. It is difficult confidently to assert how aware were the operators performing the test of these conditions, as no accounts exist. However Salge and Milling (2006) argue that the bureaucratic pressures being put upon these lower level staff was a telling factor within their actions; that is, the fear of repercussions could explain their downright dangerous actions. One cannot forget that the Chernobyl accident vividly highlighted that nuclear non-humans *are* extremely dangerous, and a new era of risk was ushered in as a consequence. It is easy to chastise these human actions in hindsight, and rightly so; but it is also easy to empathise with the mindset of a low level employee of a Soviet power station during an era where these objects were considered to be *safe*.

The next three minutes and forty eight seconds sealed the station's fate and cemented its place within the annals of history. This brief window witnessed a series of further attempts by the operators to attain the necessary equilibrium for the test to be conducted; all the while, the object was materially preparing itself for the eventual explosion. **01:19:30** saw a successful effort to increase the water level required within the steam drums, but this level was exceeded by one of the operators - his identity is not disclosed. This excess of cold water reverted back into the core and across the fuel, subsequently cooling it further and fluctuating the total power output - this was accompanied by a further decrease in steam pressure. Faced with plummeting megawattage, the operators compensated by fully withdrawing all twelve ACs from the core in an attempt to rekindle the chain reaction to a level suitable for the test to begin, which was accompanied by the partial removal of several of the manual control rods (an almost identical series of events covered in the previous paragraph). After these removals only six control rods of any kind remained within the core, less than half of the designed safety minimum of fifteen. **01:21:50** saw an increase of reactivity within the fuel due to the lack of neutron absorbent material within the core, and the manual reduction of the feed water flow rate. These two factors led to the water within the core, which was not pressurised to the standard levels as a result of the earlier drop in steam integrity, becoming rapidly hotter and raising the quality of the steam. Attempts to rectify this new core dynamic came in the form of the lowering of the ACs at **01:22:10** - one minute later the operators had temporarily stabilised the object at 200Mw (a much lower level than the designated requirement stated within the proviso of the test).

This entire sequence of events portrays a team of operators solving one problem only to create another: a rocking back and fro from one mechanical issues to another, with the attempts to solve them being enacted with vigour rather than the necessary finesse required when handling a complex machine like the RBMK, particularly in its end of fuel cycle condition. **01:23:04** witnessed the activation of the test itself, and 48 seconds later unit 4 of the Chernobyl NPP experienced two consecutive steam explosions. As previously stated, the initiation of the test began with the steam supply for turbine generator number 8 being cut off. The unavoidable increase in steam within the core (due to the sectioning off of one of its key outlets) prompted the fuel to again increase in reactivity, which in turn raised the power output of the unit. This was coupled with a manual reduction of the coolant flow rate which caused an even greater build up of steam due to the increased temperature of the coolant liquid. At **01:23:40** these evolving conditions within the core produced a rapid and steep increase in power, otherwise known as a prompt critical excursion, and as soon as the unit's foreman identified it he ordered an emergency shutdown. However, due to the almost total removal of the control rods, their extremely slow insertion rate and the lack of design support to contain a runaway reactor, this emergency termination procedure was too late in terms of time and environmental reactivity. Within 3 seconds the object had increased to 530Mw output, and it rose at a frightening exponential rate, so fast that the instruments could not keep pace with it. At **01:23:46** the reactor evaporated its remaining coolant and a massive steam build up ensued within its pressurised vessel. Nuclear reactors are built to withstand immense pressures and temperatures, but they still have their design limits. There are systems in place to release pressure build ups by simply venting excess steam into the atmosphere, but even automated systems take time, physically, to open material valves. Two seconds after this huge increase in steam occurred, unit 4 experienced two massive steam explosions caused by fuel channel ruptures.

The force of these explosions was so massive that they tore the 1,000 tonne circular lid of the reactor core clean off and thrust it into the air (Mara 2011). Nuclear reactors are sealed entities as they have to create very specific environmental conditions within their bellies to engender, sustain and, crucially, control the fission process. RBMK no4 was now open to the elements, and as air rushed into the still reacting core several more smaller explosions ripped apart the remains of the reactor's structure and its housing building (Mould 2000), thus resulting in the ruination of the western side of the Chernobyl facility and marking the start of a clean up/ mitigation operation that has lasted for 30 years.

3.5 Conclusion

This is the account of the explosive demise of unit 4 of the Chernobyl Nuclear Power Station: the material prelude which physically tore the object apart, and in the same catastrophic breath, awarded it the agency for which this research seeks to account. This chapter has taken seriously the need to account for the ontology of the non-human at the centre of the research project, its material form and the *procedures* it enacted to produce electricity. Furthermore, this account has also highlighted the very serious design deficiencies with all RBMK reactors, innate mechanical features ranging from the geography of the core, and its beehive form, the operating positive reactivity coefficient. There is no denying that the RBMK design is extremely efficient, a literally powerhouse producer of electricity, but it is intrinsically difficult to control, and as a result, unstable to operate. The Chernobyl accident was a mixture of these ontological design deficiencies, and the, arguably, insane Soviet decision to conduct a dangerous test during the most volatile period of the young unit's lifecycle; that is, at the end of its fuel cycle. This mixture of authoritarian bureaucracy and questionable reactor design commingled to produce the explosions of 1AM on 26th of April. As shall be seen in chapter 4, the pressures of the Soviet system, the expectations and the repercussions of 'failure', weighed heavy on the NPP's operators, and this could explain their lack resistance to the timing of the test, but this is only part of the answer. As a result of the accident, a large international program was set up to assess and augment the RBMK fleet — a node of action that shall be touched upon during the concluding chapter — and the very existence of such a wide ranging (and costly) programme highlights the potential risks associated with the reactor's design.

Today, all that is left in the reactor hall of the western end of the Chernobyl facility is the carcass of RBMK no4, a twisted mound of shattered metal infused with melted uranium fuel with an unfathomable half-life. However, prior to 26th April 1986, the fully functional object supplied electricity to millions of people across Ukraine, engendered gainful employment for hundreds of skilled workers, and promoted the building of an entire city just to cater for its army of human carers. Yet, other than the construction of its atomic city of Pripyat, it would be a difficult, if not impossible task to render visible a single strand of its agency and the actions it engendered during its short life. In essence, it simply faded into the background much like its brethren at Ignalina, Lenningrad and Smolensk. In the aftermath of the accident up until the present day, the physical object of unit 4 has served no positive societal purpose, other than effectively acting as a vortex for international capital. Yet its influence is still visible across a plethora of spheres of life, none more fundamentally important than that of nuclear engineering.

It is rare to find a phenomenon which closely mirrors the key tenets of a theoretical approach; however, it seems that actor network theory (ANT) was almost purposely constructed for the study of unit 4 at Chernobyl. The ability to award an object the status of an actor being of obvious importance, with the lesser known situational checklist surrounding how to operationalise this conceptual manoeuvre playing an equally imperative role. Simply put, when an object breaks, it no longer inhabits 'the background', its ontological flip consequently awards it newfound agency, which in turn prompts a host of unique actions to rectify its material malfunction. That is, the object's attracted network of actors are forced into new and dynamic patterns of action, all spawned by the physical disruption within the object. When this logic is applied to the epicentre of the aforementioned network, the object of unit 4 and its immediate geographical space of residence, the half a million liquidators drafted in to secure the flailing reactor were the first actors to bear witness to this new cauldron of agency. Granted the main research question asks how the object travelled, and one would assume that this would see the analysis move outwardly from the site. This is the case for chapters 5 and 6, but only focusing on the 'external' trajectories of the nuclear non-human would result in the glossing over of the most vibrant, panic stricken, heroic and important node action produced by its new agency; that is, the days, weeks and months immediately after 26th of April 1986, and the mission to tame the nuclear inferno.

Chapter 4

Taming the nuclear volcano: the post geoevent stabilisation of the world of the Chernobyl Nuclear Power Station.

> I was informed about accident at 4 o'clock [AM] by my kinswoman that lived in Pripyat. She telephoned me in order to find out what happened at the Chernobyl NPP. She told me that people say terrible stories about some explosion at the NPP.... I reassured her that no explosion could occur at the plant. I told her that I had on Friday a telephone conversation with one colleague that informed me about the planned shutdown of the fourth unit.... I could calm my kinswoman but I became myself the feeling of some uneasiness. I began to call my colleagues at the fourth unit of the plant. However nobody answered my calls. (Karpan, 1986, 1)

This is an extract from the remarkable (translated) account of Nikolay Karpan, the ex-deputy chief engineer of the Chernobyl NPP, focusing around his personal experiences of the geo-event. Karpan was an important actor within the station's network prior to the events of 26th April 1986, a man tasked with the co-management of the engineering staff and plant machinery, consequently ensuring that the four reactors were efficiently maintained and mechanically catered for. At the outset of his account he states that he had spent the week leading up to the accident in Moscow, undertaking a duty business trip regarding the development of additional control consoles for units 1 & 2, and only returned to his home town of Pripyat on the Friday morning, 25th April. Upon arrival he contacted the Head of Nuclear Safety, Aleksandr Gobov, and was informed that his services were not required on the day when 'the test' was planned to take place. Thus, the deputy Chief Engineer for the Chernobyl NPP, the man partially responsible for the machinery that 'the test' was attempting to improve, spent the day with his family basking in the warm spring sunshine in Pripyat. As the above extract delineates, this influential actor was not immediately 'attracted' to the geo-event and the subsequent new network/world created by the explosion. He was not awoken in the small hours of the morning by another member of the NPP's employee hierarchy, but rather by a member of his family, a person who was only indirectly connected to the station through her residence within Pripyat. This phone call took place two and a half hours after the explosion within the nuclear non-human of RBMK number 4, a notable passing of time when one considers this human actor's importance to the machinery of the NPP and the magnitude of the event that was unfolding.

This is not the place retrospectively to debate and/or critique the plant's delegation of employment responsibilities during the period leading up to the geo-event; this is a task that has been vigorously executed within the courts (Munipov, 1992), resulting in several prosecutions of the NPP's key personnel (Karpan, 2001). The purpose of providing this actor's inceptive account of his experience of the geo-event is to highlight the 'climate of chaos' that ensued, a perfect characterisation of the node of action engendered both by the event and the subsequent veil of secrecy hastily cast over the entire ordeal. It is now common knowledge that the Soviet administration of the period sought to hide the accident from the international community; this, in the geopolitical pressure cooker of the Cold War era, is not surprising. What is startling is the realisation that the NPP's human actors, its fleshy and logistically central carers, were not immediately notified about their nuclear non-human's deteriorating health. Thus, the personal accounts that are woven throughout the analysis of the material repercussions of the geo-event within the world of the Zone of Alienation enact one of the core tenets of the ANT methodological project: the maintaining of a following of the actors, subsequently facilitating their reassembling of the network/reality within which they were implicit. The construction of this ANT account entails a form of historical retrospective analysis, reassembling the materiality of the immediate impacts of the geo-event of unit 4 in a quasi-scientific manner, one only achievable due to the detachment, in space and time from the epicentre of change. The personal experiences of the actors 'on the ground' are thus tasked with engendering a window into this dangerous and chaotic event. In other words, they supplement the sterile material account by allowing the actors who, for want of a better term, were actually there, to recreate the reality that they experienced, suffered and produced. To retell the explosive second act.

What follows is a quasi chronological account of the post geo-event melee between the period of 26th April 1986, and November of the same year: the brief epoch when the nuclear non-human's newly awarded agency spawned a vast series of emergent actions tasked with, firstly regaining control of the object and, secondly, reorienting the new world it created. A fitting departure point for this account is with the heroic actions of the NPP's firefighters and on-call staff – these were the first actors drafted on site to tame the geo-event. This account will conclude at the point in time when the Sarcophagus was completed and the ripples of change spawned by the transcendental's replacement were calmed, resulting in the new world, the one which has remained for the past thirty years. During this seven month period an expansive and expensive — both in terms of finance and human life — clean up operation was set in motion, one that incorporated roughly half a million human actors (Gale & Hauser 1988; Medvedev 1990; Medvedev, 1991) and fundamentally altered the physical landscape surrounding the NPP. This empirical account of this period is segregated into action/material product packages, and each example will trace outwardly from 26th April 1986; that is, the individual accounts will conform to the chronology of the actions and their physical end goals. The purpose of this segregation is to tackle the explosive heterogeneity of the material ramifications from the geo-event, and the subsequent clean up operation, in a manner that provides each major node of action within the larger project a moment in the analytical spotlight. To reassemble the entirety of this seven month period as a homogenous whole would result in a hugely complex and obtusely entangled account. Thus, once all of the individual accounts have been produced, with their individualised chronology at the helm, a master timeline will be provided at the end as a form of quasi-chronological instruction manual - a means of illustrating how the various clean up operations took place at the same time during this seven month period.

4.1 The first emergency and the inextinguishable fire

> We didn't know much about radiation. Even those who worked there had no idea. There was no water left in the trucks. Misha filled a cistern and we aimed the water at the top. Then those boys who died went up to the roof - Vashchik, Kolya and others, and Volodya Pravik.... They went up the ladder... and I never saw them again (Grigorii Khmel, The Dispatch, 1996)

This extract is by Grigorii Khmel, a driver of one of the fire engines that was first on the scene after the geo-event and it delineates an atmosphere of confusion, desperation and death. No pictures exists from the night of the disaster; the figure 4.1 was taken from a helicopter on the morning of the 26th and it allows some grasp of the devastation caused by the explosion. The once gleaming white walls of the reactor hall, and the roof covered in grey bitumen, were replaced by a barely recognisable chasm with superheated radioactive steam/smoke billowing from its depths. This was the scene which greeted the NPP's firefighters, albeit shrouded in darkness, with the only illuminating sources being the burning bitumen on the roof of the building connecting RBMK no4 to its reactor brethren. These fires had been ignited by the huge chunks of graphite moderator which had been violently expelled from the interior of the reactor (Hawkes *et al* 1986; Mould 1988). These vital components of the pre geo-event nuclear non-human, once tasked with 'igniting' the fission reaction, subsequently fulfilled a new, similarly combustible role within the post geo-event world, one which endangered the still functioning unit 3. In the immediate aftermath of the explosion, that is, the following four and a half hours, the suppression of these rooftop fires was the most pressing concern. The geo-event caused more than thirty fires on the roof (Medvedev 1991, Mould 2000) and, if these rogue blazes were not extinguished with great haste, the structurally connected nature of the NPP could have resulted in the loss of the other unaffected units. In other words, these fires represented the first of many emergencies in the post geo-event world. What follows is an extensive account of this first stage in the post geo-event world building process, that is, the actions spawned by the nuclear non-human's new agency and their mission to bring stability to the world. In other words, this first section delineates the selfless actions of the NPPs firefighters during the midnight hours of 26th April 1986.

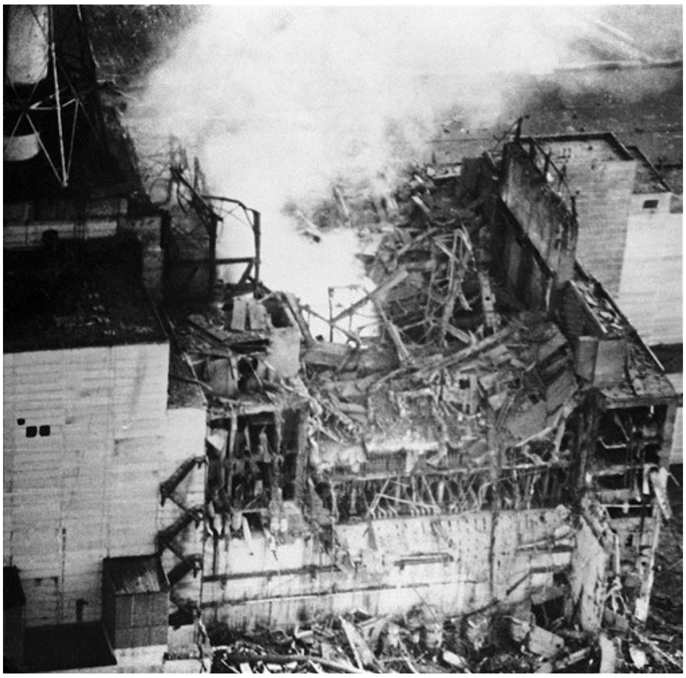

Figure 4.1: Photograph taken from a helicopter of the damage and fire (source: Gould 1990)

01.23 AM

> The first report of the accident was at 01.23 am on 26 April 1986 by an alarm on the control [panel] in the Chernobyl firefighting unit.... I was at home at the time of the alarm and rushed to the plant to take charge. - Colonel Telyatnikov (Mould, 1988, 150)

Colonel Leonod Telyatnikov was the Chief of the militarised fire brigade at the Chernobyl NPP and this statement was uttered during his visit to 10 Downing Street on 6th March 1987, to receive the Order of Gallantry, the highest award the British Fire Services Association can offer. This actor's account of the hours succeeding the geo-event will be deployed to gain a first person perspective on the firefight, consequently providing actor led contextualisation of the event and the actions engendered by RBMK's fledgling agency post explosion. From this extract, one can deduce that the fire-fighters were alerted to the existence of the geo-event by the material computer systems linking their base of operations to the NPP, and not by a human actor. There are no records of their standardised and/or regulated response time, but, in this instance it took the fire crew on call seven minutes to reach the stricken RBMK no4.

01.30 AM

The first team of firefighters was led by Lieutenant Volodymyr Pravik (Hayes & Bojcun 1988) and upon arrival he was not aware of the radioactive nature of the environment. It is difficult to comprehend the scene that awaited these first firemen, the scale of the building which houses RBMK no4 dwarfs even the largest of emergency vehicles, and, as previously stated, the most pressing emergency was on the roof. Pravyk quickly identified this and sent the first team of men up ladders to the 150 foot tall reactor hall building (Hamman & Parrott, 1987). The Lieutenant had no way of gauging the extent of the disaster and simply ordered his men to attack the rogue rooftop blazes from all sides in a desperate mission to save the sister RBMK no3. It should be noted at this stage that the heroics of these men were not aided by sophisticated protection from radiation or even smoke for that matter. They put themselves in mortal danger as they knew that there was an imperatively important job to do, and at 01.30am, they were the only people who could do it:

> When the accident occurred, in spite of whatever discord there was in the guard, in spite of everything, the whole guard followed [Lieutenant] Pravyk, followed him without looking back... Everyone felt the tension, sensed the responsibility. I only had to call a name and up he'd run: 'Understood!'. And even without listening to the end, because he'd understand what he had to do. He was only waiting for the order - Colonel Telyatnikov (Shcherbak 1989, 28)

01.35 AM

Shortly after the NPP's on-call firefighters had arrived, a second crew, Town Brigade No.6, stationed in Pripyat, reached the stricken RBMK no4 led by Lieutenant Viktor Kybenok. As the first crew were tackling the blaze on the reactor hall's rooftop, Kybenok took a search party inside the building which housed unit 4 in a mission to learn of the state of the reactor. They discovered that the core and its surrounding reactor hall were in flames. Furthermore, the unit's water system for cooling its fission chain reaction was not functioning and the emergency automated fire fighting apparatus had been completely destroyed (Hayes & Bojcun 1988). At this stage, the two commanding officers decided that the reactor hall and the machine room should be prioritised - the former was primarily tackled by the Town Brigade and the latter by members of Lieutenant Pravik's fire crew. As the roof of the reactor hall was completely destroyed (refer back to the image at the outset of this section) the Town Brigade could only fight the fire from inside the building. The roof of the machine room was still intact but on fire in several places. Thus, Pravik's brigade split up and fought the war on two fronts, both inside and from above. Colonel Telyatnikov states that the machine room was the most valuable section of the plant under immediate threat (Shcherbak 1989), and the majority of manpower was diverted to protect the unaffected objects which could still be saved. This 'value' was based purely on the monetory principles of the machinery encased within; in terms of environmental and human life preservation, the reactor hall was of primary concern.

Both nodes of action, above and inside the building, were fraught with danger. The men on the roof had to endure a greater risk of flammable bitumen igniting around them, but the Town Brigade did not have to contend with such levels of combustable spontaneity. However, their duty involved far greater levels of radioactive material - the reactor section of the building was the epicentre of the release of radiation, and these men absorbed, in many cases, lethal amounts in a matter of minutes. According to the Soviet television 'coverage' of the disaster in the weeks that followed, the levels of radiation these crews experienced were so great that the rudimentary measuring devices with which they were equipped malfunctioned when attempting to calculate the volume (Hamman & Parrott 1987; Mould 1988). Many of the firemen who died were members of the Town Brigade No.6. The first victim was Volodia Pravyk, 24 years old, the youngest member of Lieutenant Pravik's brigade. This actor was initially tackling the blaze inside the machine room, but even at this early stage mere minutes after the explosion, this section of the building was almost under control, that is, the crew of which he was a member could tame the blaze without his assistance. It was at this point that Volodia Pravyk voluntarily offered his services to the Town Brigade No.6, to aid them in the immeasurably more dangerous mission of taming the nuclear fire in the reactor room. The radiation to which he was exposed to during this voluntary duty resulted in his death:

> Volodia Pravyk, I think, was the youngest, he was twenty four. By nature he was kind and gentle, and that sometimes let him down. He never refused anyone who made any kind of request. He considered that he had to make concessions.... And so Pravyk then even went and left his guard and offered his help to the Town Brigade. Out of our guard [the militarised fire brigade of the Chernobyl NPP] only Pravyk died. - Colonel Telytinikov (Shcherbak 1989, 31)

Figure 4.2: Picture of Volodia Pravyk (source: The Chernobyl Project 2010)

01.56 AM

21 minutes passed and, as the two crews battled their respective blazes, Colonel Telyatnikov arrived on the scene and replaced Lieutenants Kybenok and Pravyk as the commanding officer of the operation (Shcherbak 1989; Medvedev 1990). The Colonel had been on a 38 day leave when the disaster had materially manifested itself and he was roughly 6 km away from the plant when he received the phone call demanding his presence. As a brief aside, once again we uncover a vitally important actor's non presence during 'the test'. At no point does the literature surrounding the disaster claim that Kybenok or Pravyk did not perform their duties with bravery and efficiency, but the presence of the man responsible for the NPP's entire fire protection service, its commanding officer, would have alleviated some of the 'climate of chaos' which ensued in the immediate aftermath of the geo-event:

> When the fire began, I was on leave… I was phoned at night, the transport controller phoned me. There was no transport all the cars were out. I phoned the town militia division which was on duty, explained the situation… I said: 'There's a fire at the station, on the machine room roof, please help me get one." He asked me my address again and said: 'There'll be a car immediately.' - Colonel Telytinikov (Shcherbak 1989, 29)

By the time Telytatnikov arrived at the station, there were only twenty eight firemen tackling the blaze (Hayes & Bojcun 1988), almost half an hour after the explosion. Upon his arrival, the two crews present had begun to ascertain the extent of the battle ahead of them. They were not only battling their traditional opponent on the roof and inside the reactor hall/machine room, but a much more intimidating foe, one so powerful that their armaments were overpowered instantaneously - a run away fission chain reaction.

As covered in the previous chapter detailing the materiality of the RBMK, the temperatures involved within nuclear fission are difficult to fathom. During normal operations, the reactor core of a RBMK can reach several hundreds of degrees, but during a meltdown, they experience an exponential increase.

Figure 4.3 details the ability of the RBMK-1500's (the bigger brother of the RBMK-1000 used at Chernobyl) to deal with a loss of coolant accident (LOCA) - the worst kind that could befall a graphite moderated, water cooled reactor. The primarily means through which the authors accredited to this graph attained their data was from the Chernobyl disaster. The table delineates the temperatures need for certain aspects of the reactor vessel to break, fail or melt. A LOCA has several stages of severity, and the lowest point of breakage occurs within the cladding at 800 degrees celsius. The most extreme case is when the fuel melts, colloquially referred to as a 'meltdown', and this catastrophic sequence is initiated at over 2,500 degrees celsius. Take note of the word *initiated,* as it is important to grasp that this is the temperature required to start this melting for the fuel; during a meltdown these levels could rise to 4,000 degrees celsius. For the purposes of an easily graspable connecting example, this is the temperature of a sun spot on the surface of our solar system's star.

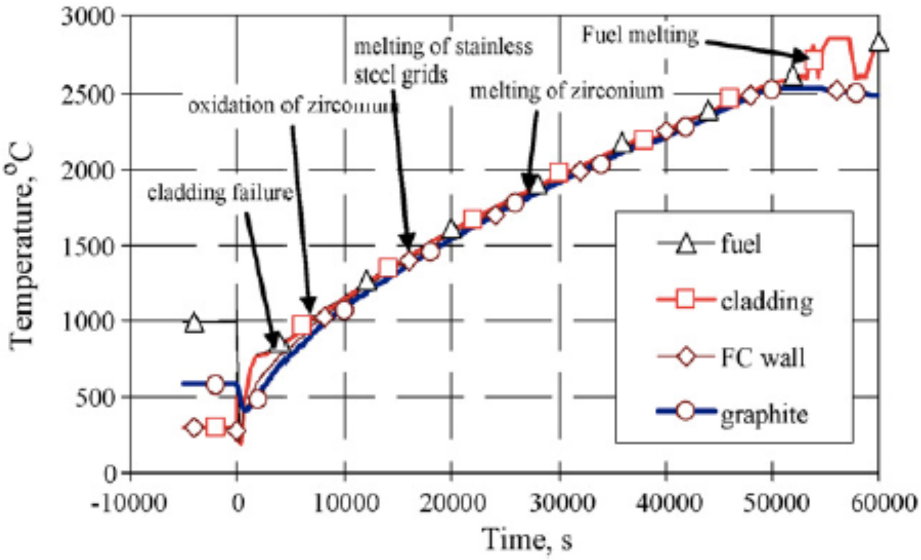

Figure 4.3: Graphical representation of RBMK-1500's ability to deal with LOCA (source Kaliatka *et al* 2008)

Even today, in the early twenty-first century, science and engineering has yet to create a means of tackling temperatures of that magnitude, especially in situations far outside the design specifications of the non-human which has engendered them. Firemen tackle fires with water - that is what they are trained to do, and this tactic was deployed by the team on the roof at Chernobyl. It proved to be a futile enterprise, though, as the fuel sustaining the blaze that they were predominately tackling was combusting graphite which features a combusting threshold of several thousand degrees. Thus, as soon as the water from their hoses came within several feet of the inferno it vaporised instantly, transforming it into super heated, radioactive steam. This posed a massive risk to these men as they were being dually exposed to steam which was so hot it could erode skin from their bones, and also the deadly radiation encased within its molecular structure. Furthermore, this aspect of the firefight highlights that the fire crews at the Chernobyl NPP had not received any formal training in the case of a meltdown. At the temperatures quoted above, water could, in effect, become an explosive agent, the polar opposite of its intended purpose. Two thousand degree temperatures possess enough energy to dissociate water into hydrogen and oxygen, culminating in an explosive mixture (Medvedev 1990, Mould 1988), one which could have contributed to more severe damage to the nuclear non-human, the emergency effort and the actors involved within it. In other words, the desperate actions of the firemen tasked with extinguishing the fire in the core, engendered by the emergent agency of the nonhuman transformed by the geo-event, were theoretically adding liquid fuel to the fire.

As this futile battle with the nuclear volcano waged on, and the traditional localised fires were being extinguished, Colonel Telyatnikov surveyed and assessed the event from a host of positions around the site. In essence, he spent roughly thirty minutes running around the various levels of the building, firstly detailing what was actually on fire, secondly assessing the risk of the existent fires spreading to vital components, and thirdly, articulating a plan for the soon to be arriving support from the neighbouring fire departments, and finally, conversing with NPP's engineering staff to gauge the most important/threatening aspects of the emergency:

> But what about the cable rooms? For us that was the most important thing. We had to go all the way round and get a good look. So all this time I was running around.... and at the same time clarified some things with the deputy chief engineer and the operational staff: what was more important, what and how..... they said: 'Yes, indeed, you have to put out the fires on the roof, because the third block is still working, but if the roof collapses and just one slab of concrete falls on a working reactor, there could be an additional depressurisation. - Colonel Telyatnikov (Shcherbak 1989, 29)

Thus, from this extract one can begin to see the constellation of actors beginning to assemble around the broken-down RBMK no4. The Colonel physically traversed the space of the plant to gain the first hand information needed to regiment his own grouping of subordinate actors, the firemen on the scene. However, connections needed to be made with the nuclear experts, the human actors tasked with caring for the RBMKs, as only they could effectively guide the Colonel to the most important areas of the plant requiring the attention of firemen. In other words, this exchange represents one of the first translations of meaning engendered by the nuclear non-human's new agency. Prior to this, the firemen were acting in an almost *subconscious* manner; they identified the location of the fires and they went to work enacting the knowledge practices awarded to them through their training. However, when Colonel Telyatnikov sought the guidance of the Depute Chief Engineer, he was seeking a translatable form of knowledge of how best to care for the still functioning units, knowledge that he would articulate in a format comprehensible to his men. Telyatnikov does not provide the name of the Depute Chief Engineer with whom he conversed; regardless, this frantic infra-actor relation provides a materially accountable example of RBMK no4's emergent agency spawning a node of action, *as-well-as* the first instance of two once disparate branches of its network combining and translating meaning.

02.25 AM

Colonel Telyatnikov had been on site for nineteen minutes and the fires in the machine room had been extinguished, and five minutes later the blazes on the main reactor hall roof (the rooftop connecting the two units 3 and 4) had been suppressed to a manageable point (Mould 1988). Therefore, one hour after the explosive geo-event, the risk of the disaster spreading to the still functioning unit 3 had been minimised through the dedicated actions of Lieutenant Pravik's bridge on the roof. Telyatnikov states that he did not even get a chance actively to converse with Lieutenant Pravyka as by 02.25 am the latter had already fallen ill and had been taken away to hospital (Shcherbak 1989, 30). The Lieutenant's medical removal from duty was the first example of a high ranking officer within Chernobyl's network falling prey to the invisible toxicity of the unstable atoms pouring out of the stricken nuclear non-human, and it left only Lieutenant Kybenok to help Colonel Telyatnikov organise the small group of firemen. These two crews of no more than twenty eight men suffered the abhorrent conditions of the epicentre of the geo-event for a further hour until the arrival of the support teams from the Kiev, Chernobyl (town of), Polissia, Ivankiv, and Rozvazhiv fire departments (Hayes & Bojcun 1988).

03.45 AM

> Somewhere around 03.45 I began to feel bad. I lit a cigarette, kept panting as before, and had a persistent cough. My legs felt weak, I wanted to have a brief sit down... There was nowhere to sit. - Colonel Telyatnikov (Shcherbak 1989, 32)

Fifteen minutes after the arrival of the supporting fire brigades the commanding officer of the entire operation began to feel the physical side effects of the materiality of the radiation; that is, acute radiation poisoning. By 05.00 am all of the localised fires had been extinguished, with the aid of the now much large fire fighting force. It was at this point that Colonel Telyatnikov was relieved of his duties and he was taken to hospital. This is where his personal account of the pre-dawn hours of geo-event end. Although the traditional fires had been tackled, and the roof over RBMK no3 secured, one massive problem still remained - the inferno within the reactor. As the morning sunlight of 26th April 1986 washed over the landscape of the Chernobyl NPP, the first of many emergencies had been successfully countered, but at a severe cost to human life. The UNSCEAR report (2000) on the health impacts of the disaster upon a heterogeneous range of population demographics concluded that the 'emergency workers', the actors who had battled to contain the immediate material repercussions of the explosion, prior to the dawn of the 26th, received the highest levels of radiation exposure. 145 people present that night were diagnosed with acute radiation sickness (UNSCEAR, 2000, 468), which resulted in 28 officially recognised deaths, six of which were members of the fire brigades. The heroism of these men did not go unnoticed by the Soviet Union, as it presented 'Hero of the Soviet Union' awards to the highest ranked officers, including but not exclusive to, Colonel Telyatnikov, Lieutenant Kybenok, and Lieutenant Pravyk. It could be argued that awarding the highest accolade of the Soviet Union was a 'publicity stunt', a means of adding a layer of heroic gloss over the Government's negligence. This may be partially true, since the 'climate of chaos' surrounding 26th April was engendered by a severe lack of communication 'from above'. As soon as the station's human actors were attracted to its emergent post-event network, either by mechanical warning systems or external means, these people acted in an articulate, calm and efficient manner, thus expelling some of the clouds of chaos at the material site of the NPP, the epicentre of the geo-event. In other words, the immediate network surrounding RBMK no4, the first actors drafted into its sphere of influence to rectify its flailing materiality, were unaffected by the translations of distant and powerful mediators. These actors, namely the firemen, represent the Latourian exception to the rule, the rare intermediaries within the network of mediators of RBMK no4.

No such glorifying awards were presented to the lower ranked firemen men, although they are commemorated within the material landscape of the town of Chernobyl by a metal monument, one part of which depicts their selfless actions during those crucially important four and a half hours. On the right hand side of figure 4.4 are the figures of the firemen and on the left that of the 'liquidators' (the men tasked with the environmental clean up operation). The inscription on the plaque reads 'To those who saved the world' - a poignant and fitting reminder of the role played by these actors within the new reality engendered by RBMK no4. Without their actions on the night of the 26th, the Chernobyl accident would have been unthinkably worse.

Figure 4.4: Monument commemorating the fireman and liquidators (source: researcher's own photograph 2015)

> We were trying to get the fires out before the radiation got us. We are firemen. This is what we were trained for. We are supposed to fight fires. We knew we must stay to the end. That was our duty. Colonel Telyatnikov (Gale 1988, 28)

4.2. The myth of the intact reactor

Subsection 4.1 has detailed the actions of the firefighters who spent several hours surveying the inside and the rooftop of the NPP's structural form, and they were the first to report that RBMK no4 was now nothing more than a twisted lump of irradiated metal, graphite and uranium. A large percentage of these actors had spent the pre-dawn hours futilely dowsing its super-heated carcass with water. Yet, as implied by the title of this subsection, mediations engendered by more powerful actors were circulating as dawn broke on the morning of the 26th April. What follows is an account of the 'myth' surrounding the intact reactor vessel. The vast majority of images of Chernobyl depict it in its current form, entombed by its steel Sarcophagus, neatly retrofitted and structurally sound. Pictures taken of the building before this structure was fitted (Figure 4.1) graphically capture the extent of the damage, and, subsequently, the 'lunacy' of the lie surrounding its status on the morning of the 26th.

The daylight hours of 26th April 1986 are sparsely documented; only a few detailed personal experiences of the activities surrounding the NPP exist, with ambiguous 'meta' accounts comprising the bulk of the material. Thus it is difficult to reassemble an accurate timeline of events during this day. In essence, the vast majority of the information 'reappears' on the 27th, the day when the officials in charge of the clean up operations made the decision to smother the reactor (Marples 1988; Mould 1988; Medvedev 1990). This impressive airborne mission shall be accounted for in due course. For now, analysis will remain squarely focused upon the minimal amounts of material from the 26th as the progression from denial to action highlights an important theme which characterises how the Soviet Union dealt with the accident in the following months.

> I was very disappointed that all information gathered in the accidental zone by senior specialists such as Dyatlov, Sitnikov, Chugunov and Akimov was accessible only for Director and Chief Engineer of the plant. This was the reason that I had to gather the necessary information about the consequences of the accident. - Nikolay Karpan (1998, 6)

Figure 4.5: Bryukhanov (source: Karpan 2001)

Figure 4.6: Fomin (source: Karpan 2001)

Victor Bryukhanov (figure 4.5) was the Plant Director of the Chernobyl facility and Nikolai Fomin (figure 4.6) fulfilled the role of the Chief Engineer for the NPP. In essence, these two actors represented the highest rung of the employee hierarchy within the station, the men whose professional reputation was fundamentally linked to the safe and efficient running of the Chernobyl NPP. It should be noted at this stage that both of these men stood trial for their role within the aftermath of accident, and their testimony from the trial shall be incorporated into this account to help reassemble the fracas of 26th April. The above extract from Karpan's personal experiences of the disaster begins to shed light on the actions of Bryukhanov and Fomin, in that they consumed the information given to them by their team of experts but did not share it with their subordinate actors. The first person accounts of this period by Karpan and Grigori Medvedev (1990), the chief engineer of the Chernobyl facility during its construction, are the only two available, and they are devoid of the political subterfuge cast over the entire incident by the Soviet Union, including Chernobyl's most senior employees. This veil of deception becomes evident within the contrasting statements between the documented experiences of the aforementioned actors and the testimonies of Bryukhanov and Fomin at their respective trials.

Bryukhanov arrived at the facility at 02.30 AM, roughly an hour after the geo-event, and headed straight to the control room of unit 4 (Medvedev G, 1990). Upon his arrival he was informed by Aleksandr Akimov, a Deputy Chief Engineer of the station, that there had been a serious radiation accident, but that the reactor vessel was still intact:

> You're saying that there was a serious radiation accident but that the reactor is still intact. What's the radioactivity in the unit now? [Bryukhanov]
> Gorbachenko's radiometer is showing 1,000 micro roentgens per second. [Akimov]

> Well, that's not much, [Bryukhanov]
> That's right [Akimov]
> Can I go ahead and tell Moscow that the reactor is intact? [Bryukhanov]
> Yes, go ahead [Akimov] (Medvedev G, 1990, 113)

Upon receiving this information Bryukhanov relocated to bomb shelter no1 constructed beneath the NPP, the safest place in the entire material landscape. This conversation represents the source of the myth surrounding the intact reactor, the first point in space and time when wrong information was passed on to the most senior official within the NPP's employee hierarchy who subsequently relayed it to Moscow. There is no accountable record of how Akimov came to this conclusion; and how this middle level manager could arrive at this outcome at the exact same time that Lieutenant Kybenok's fire crew was actively fighting the blazes inside the ruined reactor hall is, for want of a better term, baffling. Regardless, this extreme instance of communication ineptitude between the actors actively working to save the nuclear non-human culminated in the director of the NPP telephoning Vladimir Vasilyevich Marin, the Director of Nuclear Power within the Communist Party, at his private residence at 03.00 AM and relaying incorrect information (Shcherbak 1989, Medvedev G, 1990). This is the moment when the network surrounding Chernobyl exponentially expanded, the moment when this transportation of knowledge kickstarted the mobilisation of numerous specialists, party members and high ranking military personnel. This emergent constellation of actors will be covered in the following section. It also represents a major discrepancy between Bryukhanov's legal testimony and the personal account of Medvedev. When asked in court about his actions that night, Bryukhanov stated that:

> The communication department manager informed me that the telephone line is ready and I started to report to the head of central directorate: The accident happened, 4-th power unit is destroyed, I don't know any details yet. (Karpan 2001, 6)

Akimov was, according to Medvedev, the source of the misinformation, the root cause agency which shaped the direction of the following hours of action, now preoccupied with cooling a reactor vessel which was believed to be intact. However, he never stood trial, his name does not appear within its transcript, and Bryukhanov does not mention him during his statement of defence. This is not the place to explore this omission, due in part to the *invisibility* of the decision making process which resulted in the accused standing trial. Regardless, these contradictory accounts of the actions of that night begin to shed light on the embarrassing and potentially catastrophic nature of 'the myth of the intact reactor'. As stated above, the application of water to a non-pressurised, out-of-control fission reaction,could result in the dissociation of water into its explosive composite elements due to the immense temperatures associated with this *unique* material situation. The fire crews were already pounding the open reactor with hundreds of gallons of their liquid ally from the rooftop and inside its hall, simply enacting their inadequate training. Due to the 'belief' that the reactor was still intact, the message from Moscow to Bryukhanov at 04.00AM was "Make sure the nuclear reactor is kept cool at all times." (Medvedev, 1990, 117). So, this is what he instructed his subordinates to do - pump even more water into the shattered and frighteningly hot core of RBMK no4.

One and a half hours passed until the Chief Engineer Fomin arrived in the bomb shelter at 04.30 AM and he immediately demanded a status report from his higher ranking subordinate, Akimov. Once again, the Depute Chief Engineer relayed the same information and Fomin echoed the advice of the Central Directorate; that is, feed water into the system to keep it cool. This order was carried out by the last remaining emergency feed water system no2, a complex machine which shared a reservoir with RBMK no4's sister unit. The connecting pipes from the tank of coolant to the reactor vessel are capable of channeling hundreds of gallons of water into the system in a matter of minutes (IAEA 1999, Kaliatka & Uspuras 2000); however, their effectiveness relies, rather obviously, upon the pipeage being intact and fastened, crucially, to a hermetically pressurised core. It is useful to think of the reactor vessel akin to a cylindrical tin, sealed at both ends, and the emergency feed water system entered this sealed container through pipes which burrowed through its vertical walls at specific points. When the water was sent through the system prior to the geo-event, the enclosed nature of the object restricted the liquid from escaping, thus facilitating its (pressurised) cooling properties to be enacted upon the vessel's hot interior. However, the gas explosion within RBMK no4 tore the lid off the reactor core, and the impact of the blast forced its base down several floors into the basement of the building. In essence, only the vertical walls of the unit remained partially intact - the exact structures which housed the emergency feed water system's intakes. Therefore, our metaphorical cylindrical tin now lacks a solid base, sealant lid and complete vertical walls, and hence its previous use as a hermetical containment structure was no more. When the emergency coolant was pumped into the believed-to-be intact core, all that the system now achieved was the catastrophic mixture of said water with the intensely irradiated graphite and twisted fuel rods. This violently ionised liquid subsequently seeped downwardly into lower floors of the building. In other words, not only was this course of action dangerous with regards to the dissociation of water, but it also contributed to the spread the of huge amounts of radiation on and below ground level.

Throughout this account thus far, the levels of radiation experienced by the aforementioned actors have yet to be actively detailed. Due to the nature of the event, it is a given that the exposure which they endured was extremely high, life ending in several cases. The reason that the presence of radiation has been 'assumed' up until this point is due to the obvious nature of its unwanted residency; that is, the explosive discharge from RBKM no4. The ontology of the entity of radiation will be covered in depth in Chapters 5 and 6. Prior to the brief epoch of 'the myth of the intact reactor', every action undertaken had been tasked with eradicating the problem. The aforementioned use of the emergency feed water system was *intended* to achieve this goal, but due to the shocking miscommunication between members of the facility's management, this course of material actions heightened the level of radiation rather than reducing it. Thus, 3 hours after the explosion, the radioactivity within the station was awarded an additional mobilising characteristic, one which actively increased the charge within several areas of the plant. In a bid to highlight the physical danger inherent within the mediation surrounding the reactor's physical form, a brief and illuminating scientific excursion shall be taken (the concept of radiation will be fully explored in chapters 5 and 6).

The r-Unit, or roentgen, is, by contemporary standards, an outdated unit of measuring ionising radiation, and it is applicable only when accounting for gamma rays, the most powerful and damaging form of radiation (Sinclair 1958). Its usefulness was outlived when the measurement of the Rad was introduced, as it could measure all ionising radiation, and not just gamma rays (Hodgson 1999). Throughout the discourses on the Chernobyl disaster, the roentgen is the predominant measurement cited, and its perpetual use alludes to the severity of the situation within the NPP. In 1934, the International Commission on Radiological Protection (ICRP) set a limit of 0.2 roentgen per day, which was lowered to 0.3 roentgen per week in 1950 (Clarke & Valentin 2008). These figures represented the internationally recognised *maximum* 'acceptable' dose of gamma radiation to which an individual could be exposed, the assumption being that any increase could result in health issues. As with all scientific forms of measurement, the nexus between the statistical unit and multiplying variable is crucial, and at first glance, the relationship can be slightly deceptive. For example, the aforementioned *decrease* in acceptable level sees a rise in the statistical unit but a change to the multiplying variable, that is, shifting from exposure from a single day to a week. Thus, equipped with this slice of scientific logic, attention will now return to 26th April at approximately 04.45 AM.

> You had the impression you could see the radiation. There were flashes of light springing from place to place, substances glowing, luminescent, a bit like sparklers - Colonel Telyatnikov (Gale 1988, 27)

The above extract delineates the subjective experiences of Colonel Telyatnikov encountering the radiation emanating from RBMK no4. The graphite fire within the core awarded the radioactive isotopes a form of vertical transportation, a vehicle that subsequently spread its toxic legacy around Europe. However, as previously stated, the vast amounts of water being pumped into the shattered core by the emergency feed water system also resulted in the spread of ground level radiation. Prior to this unwelcome series of events, the levels experienced within the wrecked reactor hall reached 10,000 roentgens per second (Marples 1986; Medvedev, 1990). However, the material repercussions of 'the myth of the intact reactor' saw this horrifying level rise to a scarcely believable 15,000 roentgens per second due to the mixing of the emergency coolant with radioactive debris. Contrast these figures with the internationally regulated 'safe limits' and one can begin to ascertain the peril in which the rescue workers had inadvertently placed themselves. One might argue that any increase upon a starting point of 10,000 roentgens per second is merely hastening the inevitable, but a mindset of this nature excuses the actions of the NPP's most influential actors, men tasked with the protection of the nuclear non-humans, and, most importantly, the people under their command: 5,000 roentgens per second is enough radiation to kill ten people. If every level of the rescue operation had worked in unity, Hospital no 6 in Moscow may have been able to save several of the firemen who died.

Hours passed as the NPP's management reiterated the instruction to keep 'cooling' the reactor. Safe in the protective bunker deep beneath the plant where not even gamma rays could penetrate its walls, Bryukhanov was in constant contract with the Central Directorate and the incorrect consensus that he and Fomin had reached never faltered. Rather shockingly, as the geo-event progressed, Bryukhanov's mediation of it mutated, subsequently alluding to a minor incident, a situation which should not affect the plant's operations, nor, crucially, his reputation:

> The reactor is intact. We are supplying water to it. There was an explosion in the emergency water tank in the central hall. The radiation situation is within normal limits. One man has been killed." Bryukhanov (Medvedev, 1990, 120)

The above extract represents his communications to the Central Directorate, and it delineates an incident which would barely be representable on the International Nuclear Event Scale (INES). Up until Fukushima, Chernobyl was the only level seven nuclear 'event' the industry has ever experienced. Thus, it is galling to learn that the Plant's Director actively sought to downplay the significance of the accident, particularly when one explores the material and human repercussions of his mindset. Said mediation delineated a level zero event, one at the most, that is, a 'deviation' or 'anomaly', respectively.

At 07.00 AM, a full four hours after the initial order to cool the reactor was given, the Deputy Chief Engineer Karpan arrived at the bunker. Due to the exclusionary nature of the information presented to the NPP's Director, Karpan had to spend one hour actively reconstructing the geo-event through a series of informal 'interviews' with eye witnesses, people who had been on the scene for several hours by this point. This actor's actions during the following hours represents the first accountable relation which stood against the hegemony surrounding the intact reactor, the inceptive agency which debunked the myth and, crucially, directed action towards the 'real' material goal of taming the shattered reactor. The significance of Karpan's arrival and his subsequent actions should not be understated. Upon returning from his excursion around the plant tasked with piecing together what had happened a few hours earlier he reflected that:

> Already before 10 in the morning I could visit together with the head of nuclear and physical laboratory Anatolyi Kriat the central hall and control room of the third unit, the control room of the demolished fourth unit and some other places. I could also examine just from being outside in the site of the plant the status of the destroyed fourth unit. (Karpan, 1986, 6)

This extract firstly delineates a substantive 'trip' around the site, at a time when the levels of radiation were at their peak, simply to attempt to understand how the accident had occurred. Secondly, Karpan states that one could readily gauge the status of RBMK no4 from the outside of the building with the naked eye, thus casting further doubt upon the motivations and actions of the NPP's Director. Upon returning to the bunker, he was assigned the task of assessing whether or not the natural air cooling was sufficient to prevent the fuel assemblies from melting. He stated that this task was assigned to him as the specialists directing the actions of the emergency operations, transfixed on cooling the core, were unsure if the water could reach the entirety of the active core.

Due to his understanding of the techniques developed by the RMBK's designers, Karpan could quickly conclude that there was no point in circulating water in and around a destroyed reactor. Partially due to the aforementioned mixing with radioactive elements, but also as the air cooling experienced during the six hours since the accident was enough to minimise the risk of sustaining the fission reaction. He quickly prepared his report and handed it to his superior, Fomin. This report represented a crucial turning point for 'the myth of the intact reactor', *as-well-as* rendering visible the agency which engendered the following day's actions; that is, the airborne mission to 'drown' the reactor. Within said report, Karpan recommended that the use of the emergency water cooling system had to be stopped immediately, and that the neutron absorbers had to introduced into the core to end the fission reaction, something to be achieved by dropping boron acid directly into the unit. Furthermore, he stated that a helicopter must be deployed to photograph the damage, and that dosimeters must be placed outside the unit and along the road to Pripyat, to enable the 'following' of the radiation and, if need be, to facilitate the timely evacuation of Pripyat. Akin to most of the people who were working to save the reactor, Karpan's family lived in Pripyat and after surveying the geo-event, he realised that Pripyat had to be evacuated. However, Bryukhanov was quick to inform him of the limits of his power, stating that "he [Karpan] had no right to take the decision about evacuation of all these people." (Karpan, 1986, 8).

Due to the power and influence of Bryukhanov and Fomin within the NPP, literally no one had the authority to question or override their orders concerning the state of the nuclear non-human. It was only when a specialist team of external experts was flown in from Moscow that the madness of these two men was subdued. More than one hundred men had been hospitalised trying to keep the emergency water system functioning (Karpan, 1986, Medvedev, 1990). Granted this was a physical repercussion of the geo-event, but their extreme exposure, the amount over and above the ambient levels experienced by all of the emergency actors, was based fundamentally upon the mediation of the reactor's status concocted by Bryukhanov and Fomin. At 09.00 AM a YaK-40 helicopter departed from Bykovo airport Moscow with a consort of high ranking experts on board. This collective of actors was referred to as 'the emergency task force' and it included: Prushinsky, chief engineer of Soyuzatomenergo (the company responsible for the construction of the RBMK reactor fleet), Ignatenko, the deputy director of Soyuzatomenergo, Konviz, the deputy head of Gidrioproyekt, Polushkin, a representative of NIKIET, and the main designer of the RBMK, Ryazantsev (Medvedev, 1990, Mould 2000). This task force arrived at the site of the NPP at 01.45 PM, 26th April, and instantly surveyed the damage from a helicopter. This flight represents another step towards the end of 'the myth of the intact reactor'; and, upon their arrival at the bunker, they brutally informed Bryukhanov of this 'mistake' and physically took him out to survey the damage in the light of day. However, even after this journey, the emergency feed water system continued to attempt to pump coolant into the shattered reactor. This course of action continued until 7.00 PM, when the systems tanks ran dry.

This initial task force was supplemented by a much higher ranking cohort of officials later in the evening of the 26th, men with sufficient power actively to relieve Bryukhanov of control of the emergency operation. Their flight departed from Kiev at 4.00 PM with the following personnel on board: Yu Shadrin, senior assistant to the attorney general of the USSR; V Martin, the nuclear power secretary of the Communist Party Central Committee; A Semynov, deputy minister of energy; A Meshkov, the first deputy minister of medium machine building; M Tsvirko, director of Soyuzatomenergostroy; V Shevelkin, deputy director of Soyuzatomenergostroy; Ye Vorobyov, deputy minister of health of the USSR; and V Turovsky, deputy director of the ministry of health of the USSR (Medvedev 1990; Mould 2000). This government commission comprised extremely powerful actors, and it would have included the most senior members of their respective departments/companies if the true nature of the accident had been relayed by station Director Bryukhanov. Upon arrival at the site of the plant at 9.00 PM, Marin and Shasharin were immediately taken to the NPP to survey the damage. Prior to this journey, Marin, the highest ranking and subsequently more influential actor of this secondary team, was still under the impression that this was a minor accident, but, this impression changed as soon as he surveyed the scene of devastation surrounding the nuclear non-human:

> At the time we thought something was burning on the floor; it never occurred to us that it was the reactor. Marin was beside himself with rage, cursing, and gave a graphite block a heavy kick. We did not realise that the graphite was emitting 2,000 roentgens per hour - and the fuel, 20,000 - G Shasharin (Medvedev, 1990, 157)

At roughly 10.00 PM on the 26th April, Marin and Shasharin had returned to Pripyat and gathered with the other members of their cohort in the office of the first secretary of the Party Committee. This meeting represents the demise of 'the myth of the intact reactor'. Furious at what he had surveyed, Marin screamed "Bryukhanov! You've been telling us all day long that the radiation situation was normal. What about the graphite?!" (Medvedev, 1990, 160). Bryukhanov attempted to claim that he believed the graphite scattered around the landscape to be from the contraction supplies for the never-to-be-built units 5 and 6. However this was obviously not the case. Thus, equipped with the correct information surrounding the state of RBMK no4, this task force began to construct a new plan, one which would dictate the actions of hundreds of people for the following weeks.

This account of the epoch characterised as 'the myth of the intact reactor' delineates an unknown node of emergent actions, spawned by the agency of RBMK no 4, and directed by the NPP's Director in Chief Victor Bryukhanov, with the aid of his Chief Engineer Fomin. The account portrays a frantic, misconceived and ultimately futile mission to cool a nuclear reactor which had been physically destroyed by the steam explosions several hours earlier. The secrecy surrounding the information passed to Bryukhanov can be accounted for when one considers that the law within the USSR stated that any industrial accident, be it nuclear or otherwise, had to be kept as a classified State secret (Lusted 2011). Thus, the station's director may have been operating with this legality in the back of his mind, but this does not excuse his insistence on perpetually cooling a shattered reactor, thus dooming several firemen and operational staff members to an agonising death at the hands of unstable atoms. Furthermore, his blatant obscuring of the truth with regards to his communications with the Central Directorate placed the entire emergency operation in jeopardy, especially when considering that upon arrival, the emergency task force, in effect, had to spend valuable time articulating a plan of action to deal with the *actual*, ontological, situation. This team of experts had prepared for the type of incident described in the epistemological veil hastily cast over the geo-event by Bryukhanov, and so the reality of the geo-event was a shock to everyone involved. Thus, in the morning hours of the 26th of April 1986, the first true mediator of Chernobyl's new emergent network appeared and enacted influence over his fellow actors, both human and nonhuman. Years later, Bryukhanov was found guilty of extreme negligence and a blatant misuse of his power and was subsequently sentenced to ten years in prison. During his sentencing, the Judge stated that:

> Director Bryukhanov, who arrived to the station about 2o'clock in the morning, did not implement the Plan of measurement for protection of the station personnel although he knew exactly that levels of radiation were high... for private gain, [Bryukhanov] deliberately hid this fact (in attempt to show that everything was OK). Abusing his position, Bryukhanov sent a report to higher organs which deliberately understated estimates of radiation levels. Hiding the true information about the accident resulted in radiation exposure of the station's personnel and population of the region. (Karpan 2001, 46)

This is a damning account of the actions of a man who produced 'the myth of the intact reactor'. The purpose of detailing the events of the morning hours, post geo-event, has been to reassemble the material ramifications of the explosion, and subsequently allude to how the agency of RBMK no4 spawned and influenced the actions of the actors implicit within the emergency operation tasked with taming its meltdown. As previously stated, Director Bryukhanov embodies the tenets of the ANT mediator; a translator of meaning, intent on influencing other actors for specific ends. His agency, which was a hybrid engendered through his own subjectivities focused around self-preservation and his connection with the station, manifested itself within the material realm, producing several ontological realities, and as a result hampered the emergency operation, consequently condemning several men to their deaths. Indeed:

> By 3.00 in the morning of the April 26 you already knew that a level of radiation nearby the 4th power-unit was 200 roentgens per hour. Did you understand that the situation might get worse? [The Public Prosecutor]

> I knew that the dose rate was mainly determined by isotopic iodine radiation in the atmosphere so I was sure that the dose rate would decrease. As for 200 roentgens per hour, it was registered only within fields of vision. [Director Bryukhanov]
>
> Then why didn't you evacuate people from the dangerous zones? [The Public Prosecutor]
>
> I ordered to evacuate redundant personnel, but the reactor had to be observed. [Director Bryukhanov] (Karpan, 2001, 10)

Armed with the information rendered visible by means of this account, one can clearly see that even during his trial, sworn under oath to tell the truth and nothing but, Bryukhanov still distorted his representation of the event and mediated sections of his actions in a desperate bid to save himself.

All of this has interesting ramifications for this world of risk, and its mediation by these two important actors. Many risks cannot be identified, quantified and acted upon without a sustained series of actions tasked with rendering visible the ontological and connecting it to epistemological constructs (risks). The magnitude of the pressures and agencies to which these two men were being subjected must be acknowledged: the responsibility of caring for human life and machines fell to Bryukhanov and Fomin, and the demands of the situation are difficult to fathom. Regardless, attempting to mediate the risks of the situation in order to protect their own interests cannot be viewed in a favourable light. Thus, in this instance, the world of risk was much more volatile and dangerous than the representation propagated by the facility's two most influential actors. RBMK no4 was in fact very broken, and several treacherous actions had to be taken to mitigate the post-event risks.

4.3: 27th April and the airborne battle of Chernobyl

Thus far, the heroics of the firemen and the 'madness' of the facility's commanding actors have been examined. Two sets of interconnected nodes of action, inceptively engendered by the new agency awarded to RBMK no4 post geo-event and subsequently guided by powerful human actors implicit within the network surrounding the stricken nuclear non-human. The day of the 26th passed by in a flash, and the majority of it was spent assessing the most effective way of tackling the immense heat signature pulsating from the belly of RBMK no4. As covered in the previous section, the arrival of Karpan at 07.00 AM signalled the emergence of the following days'actions; that is, the incisive moment when the actor partially responsible for the agency that directed a new series of actions was attracted to the nuclear non-human's new network. He stated in his report that large amounts of boron acid had to be dropped into the reactor as soon as possible, but, to his disgust, he was informed of the "impossibility to find the necessary amount of boron needed in order to exclude the possibly of initiation of a self sustaining chain reaction" (Karpan, 1986, 8). This logistical unavoidability resulted in a series of actions within the town of Pripyat, and which ultimately, would unfortunately lead to an increase in the magnitude of the reaction occurring within RBMK no4. The next accountable set of relations associated with this course of actions becomes visible at 4.00 PM in the atomic city of Pripyat.

> About four in the afternoon on Saturday, 26 April, the members of the Government Commission began to gather. The idea had been proposed of loading sand onto helicopters and scattering it over the reactor. Whose idea it was, I can't say. The debates there lasted a long time. Was lead necessary? Was sand necessary? Commands were very quickly given and then countermanded. It was obvious why, there had never been a situation like it before. Something fundamentally new had to be found. - Aneliia Perkovska (Shcherbak 1989, 57)

Perkovska was the secretary of the Pripyat Komsomol Town Committee and was present during this seemingly chaotic meeting designed to find a solution for taming the out of control reactor. It should be noted that this meeting took place before the arrival of the more senior task force from Moscow, when the emergency feed water system had 3 hours of coolant remaining. Upon conclusion of the aforementioned meeting in Pripyat, it was agreed that sand was to be used as a means of subduing RBMK no4 (in the absence of boron). This was not an ideal solution: the use of specific neutron absorbers was the preferred one, but the use of boron acid was not possible on the afternoon/night of 26th April. Thus, the agency of RBMK no4 sparked an improvised series of actions within the increasingly irradiated landscape of Pripyat, one involving the gathering of as much sand as possible to aid the proceeding aerial battle for Chernobyl:

> I was given the first task: spades were to be brought to the 'Pripyat Cafe'; we had to go and get those spades, around 150 of them, and the others went to the hostels to collect young people. The young people came. Around eleven in the evening a truck came with empty sacks, and we started to fill the sacks with sand. Iurii Dobrenko (Shcherbak 1989, 58)

Dobrenko was an instructor within the Pripyat Komsomol Town Committee and this extract alludes to the ad hoc nature of the evening of 26th April. It delineates a team of actors who had no official connection to the NPP, except externally through their residence of Pripyat, tasked with gathering huge amounts of sand without the aid of heavy machinery, and loading it onto a truck bound for the launch site of the vast fleet of helicopters which were on their way to the site.

The time was now approximately 9.00 pm, 2 hours after the emergency feed water system ran out of liquid and the 'poisoning effect' within the core of the nuclear non-human had come to an end. This material situation occurred within the RBMK during standard operations, and it can be characterised as an increase in a byproduct of the Fission reaction, Xenon-135. Simply put, this gas acts as a neutron absorber, and it is an unwelcome visitor within the reactor vessel during normal operations. The appearance of Xenon-135 is a result of the decay of Iodine-135 and an equilibrium between the two is carefully maintained so that neither gas can have a detrimental effect upon the smooth running of the reactor (Afanas'ev *et al* 1991). If one of these elements is allowed to gain supremacy, it will absorb a huge amount of neutrons away from the nuclear fuel and the end result will be a decrease in the reactivity of the core. Once again, during normal operations, this situation would be most unwelcome, but, in the immediate period after the geo-event, this gaseous absorbent of neutrons became an advantageous side effect of the RBMK's design as its presence reduced the risk of a self-sustaining chain reaction. Xenon-135 has a half life of roughly nine-and-a-half hours (Fedosov 1993), and only a huge volume of the gas would prolong its 'poisoning effect' upon the stricken nuclear non-human. By 7.00 pm the gas had completely decayed and its absorption of neutrons away from the fuel assembly had ceased. This posed a massive issue for the emergency operation, as the fast evolving material composition within the reactor vessel led here to a sharp increase in its production of radiation. This ontological aspect of the RBMK has fascinating implications for the philosophical awarding of agency to the nuclear non-human. This evolving materiality within its core happened without human intervention, and the resulting change in its form *forced* humans to act in accordance. Thus, it is another prime material example to legitimise this research's promotion of RBMK no4, the nuclear non-human, as the central actant of the network in question. As a brief aside, this unavoidability was at the forefront of Karpan's mind when he advised the immediate injection of boron acid, a neutron absorber, into the core.

The purpose of accounting for this mutation within the nuclear non-human is to render visible the *invisible* aggressor which was coating the landscape of Pripyat, at the same time as residents of the city were beginning to collect sand. Approximately two hours had passed since the poisoning effect had run out of gas, and over that time, the levels of radiation within the landscape of the city had seen a notable increase. The actors collecting the sand did so without any protective clothing. Figure 4.7 is an image of Karpan's (1986) personal workbook, the journal he used to record the levels of radiation within the sites of measurement around the landscape of Pripyat. No accountable information exists explaining where each 'chosen point' represents within the city; regardless, one can readily identify from the chart that the dose rate doubles in almost every area, and in some cases it even triples, between the hours of 7.00 pm and 10.00 pm.

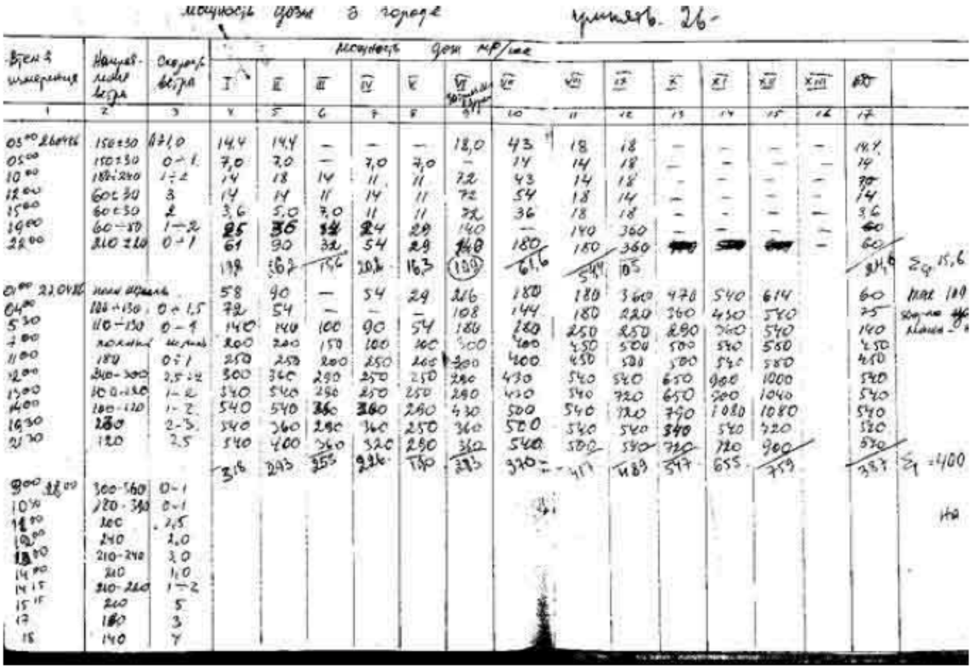

Figure 4.7: Karpan's personal workbook (source: Karpan 1986)

The longer the core remained open to the atmosphere, the more radiation it emitted into the environment, and hence it was imperative to collect as much ammunition for the following day's helicopter assault. The sand was taken from the 'Pripyat Cafe' (figure 4.8) to the river station for packaging, then quickly transported to Central Square (Shcherbak 1989).

Figure 4.8: Pripyat Cafe (source: researcher's own photograph 2015)

The aerial bombardment of the nuclear non-human featured two 'phases', characterised by both the different materials used to 'drown' the reactor and the physical augmentations made to the helicopters. During the first phase only sand was dropped, and the cargo of the second comprised a mixture of substances, each with its own specific material effects upon the core. As previously mentioned, the boron was included to absorb neutrons away from the fission material, and this element was supplemented by the sand, lead and dolomite (Hawkes *et al* 1986). The lead was used as it would act as physical barrier once it had been melted by the extreme temperatures within the nuclear non-human, and during this material liquidation it would subsequently absorb heat. When exposed to high temperatures, dolomite produces huge amounts of carbon dioxide, which, it was hoped, would starve the combusting graphite of oxygen, thus extinguishing its super heated-blaze. The key logistical issue that the emergency operation faced was the locating of these elements, as only sand could be sourced from the immediate locale surrounding the NPP. Thus, the boron had to be transported from a supply depot in Kiev, and the lead and dolomite from neighbouring countries (Mould 1988), all of which took time. Rather than simply waiting for the other components to arrive, the operation took the decision to start dumping sand alone into the ravine where RBMK no4 once stood.

Figure 4.9: Helicopter preparing for 'bombing' run on RBMK no4 (source: Kostin 2006)

The above image was taken from a helicopter hovering to the north of the NPP, patiently waiting for aircraft in the forefront of the picture to finish its 'bombing' run. As this airborne operation used military vehicles and airforce pilots, a high ranking member of the USSR's military appendage was drafted onto site to direct the vast series of actions required in 'drowning' the reactor from above. Major General Nikolai Timofeyevich Antoshkin, the deputy commander of the airforce of the Kiev military district, was the man who took control of the airborne operation (Hawkes *et al* 1986; Shcherbak 1989; Mould 2000); and, by the evening of 26th April, he had already been attracted to the network swirling around the nuclear non-human:

> Go immediately to Pripyat. The decision has been taken to dump sand on the damaged nuclear reactor. The reactor is 100 feet high. Helicopters are clearly the only technology suitable for this job. In Pripyat act according to the circumstances. Keep in constant touch with us. - Kiev Military District (Medvedev 1990, 176)

The above extract delineates the orders issued to General Antoshkin by his superiors in Kiev, and it renders visible the connection between the aforementioned 'chaotic' meeting within Pripyat Komsomol Town Committee's head office, regarding the use of sand, and the branches of the NPP's network in distant spatial locations — in this instance, 50 km away in Kiev. This order to the General subsequently resulted in his movement into the world of the NPP, but also the material relocation of dozens of military helicopters, due to their normally distant base of operations. In other words, this set of relations represents another example of agency overtaking action, and the ability of a group of influential and informed actors within the city of Pripyat to spawn a vast mobilisation of personnel and machinery.

It was now late evening, and the spring light was fading. Due to the inaccurate system the helicopters would be utilising to drop the sand into the reactor, the complete lack of any radar or digital targeting systems, the daylight hours represented the only time when the airborne mission could commence. During the midnight hours of 27th April, a full day after the explosion, preparations were being made to facilitate the incoming aircraft. The Chernobyl NPP was not a military facility, neither was the atomic city of Pripyat. Nothing within the physical landscapes of either settlements had the natural ability to house dozens of helicopters. Thus, akin to the ad hoc nature of the entire operation, General Antoshkin designated a large enough space within Pripyat to house the incoming fleet of aircraft - the square immediately outside Party Committee Offices, otherwise referred to as 'central square'.

This location is represented within figure 4.10, a site that is both close to the river where the sand was being collected, and one of the few large open stretches of land partially devoid of trees in the entirety of the city. Due, once again, to the non militarised design of the atomic city, it lacked the infrastructure needed to orchestrate a single helicopter flight, let alone a huge operation. However, this was an extraordinary situation, and the necessity of an air traffic control centre was met by means of the rooftop of the Polissya Hotel (the large building to the south west corner of the square), one of the tallest structures within the built environment. As dawn broke on the morning of 27th April, the first two helicopters arrived at the makeshift heliport in the central square of Pripyat, shepherded carefully onto landing pads by General Antoshkin, who had situated himself on the rooftop of the nearby hotel.

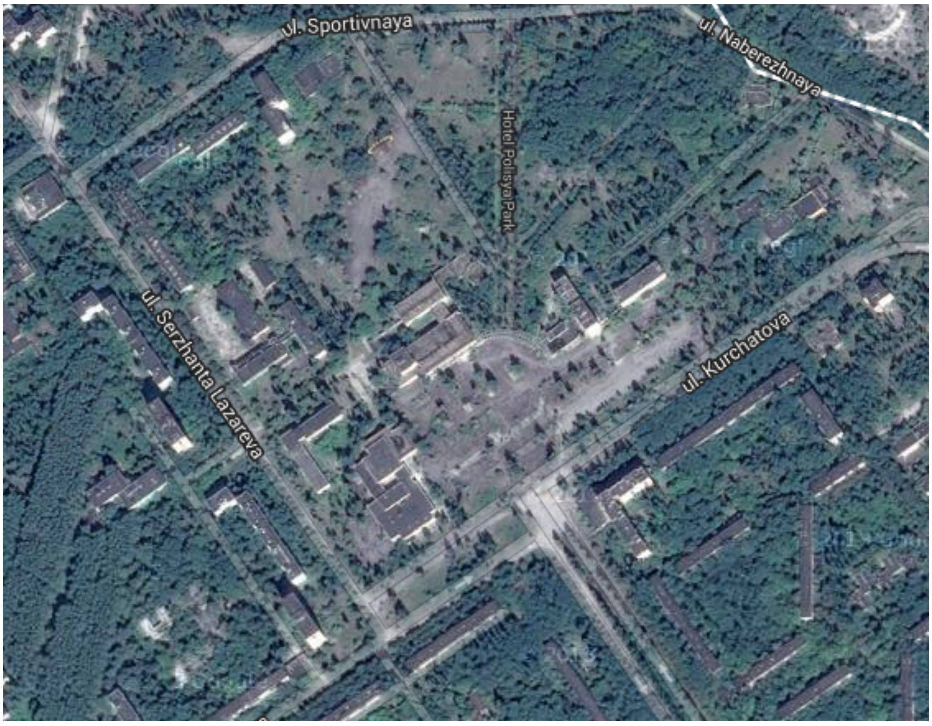

Figure 4.10: Pripyat central square (source: GoogleMaps)

At this juncture, a moment of logistical elaboration is required to aid understanding of the difficulty and subsequent peril that these pilots had to overcome. As stated in a previous section, the majority of the release of radioactive material from RBMK no4 was by means of the fires which burned within its interior. Simply put, the material on fire was radioactive in nature, and had spent the past three years within a nuclear furnace being perpetually hounded by unstable atoms. Once the poisoning effect had ceased, the temperatures of the fuel started to rise, and a larger percentage of the graphite moderator began to combust, thus transporting its compositional atomic structure, unstable and non, vertically into the atmosphere. As a brief aside, this 'type' of radiative release is in stark contrast to the recent incident at the Fukushima NPP, where the vast majority of its spread of radiation was achieved through ground water and not a fire. This mechanism limited its global transgressions due to the restricted mobility of water, but maximised the pollution of its surrounding landscape through the saturation of the soil with intensely radioactive liquid. The verticality of the release from RBMK no4 presented General Antoshkin and his pilots with a logistical nightmare, as the only way for the helicopters to drop their payloads into the shattered reactor was from directly above it. In other words, they would have to fly directly into the 'chimney' of heat and radiation billowing upwardly from the belly of the nuclear non-human. Furthermore, the flightpath in and around the station was made all the more hazardous by the unit's huge ventilation stack which rose one hundred and fifty metres into the air. The coupling of this 'intrusive' object with emergent cross winds and the radiation resulted in a semi-suicidal-mission, one akin to the heroic actions of the firefighters during the previous night.

The first two aviator actors attracted to the NPP's network were B. Nesterov and A. Serebryakov (Shcherbak 1989; Medvedev 1990) and the helicopters they used were the USSR made MI-6. These two men were responsible for the surveillance of the site and, together with General Antoshkin, they articulated a flight plan which was followed by the other pilots who arrived on the 27th. These first reconnaissance flights were most dangerous, as these men were literally flying into the unknown. Not only did they have to chart a safe path for the bombing mission, they also had to measure the levels of radiation at specific heights in order to calculate the optimum range for dropping their payload, taking into consideration the innate velocity of the 'bomb' and their exposure of radiation. After a delicate dance with altitude and unstable atoms, these actors agreed that the helicopters could not descend lower than 100 metres above the nuclear non-human, as below that height the radiation levels spiked wildly to above five hundred roentgens per hour. In other words, during the four minutes needed to manoeuvre into position, take aim and subsequently drop the packages into the reactor, these actors could receive between 20 and 80 roentgens baseline dose (Hamman & Parrott 1987, Medvedev 1990). A staggering amount when one casts attention back to the ICRP recommended limit of 0.3 roentgens per week. These pilots were hence absorbing this limit literally thousands of times over in a matter of minutes.

Upon completion of these scouting flights, the time was approximately 2.00pm, and during this process General Antoshkin had ordered the high ranking members of the emergency task force to begin loading the sand into bags in preparation for the bombing runs. Labour was in extremely short supply by this time on the 27th as the evacuation of Pripyat was in full flow (which will be accounted for in the following section). Thus, high ranking and 'intellectual' actors, who found their 'enlistment' for manual labour a bit of a shock, began this intense physical duty surrounded by radiation. This node of action renders visible a tension between the two 'commanding' actors of the emergency operation, with General Antoshkin coordinating the military side of the effort and Boris Shcherbina, representing the highest ranking government official, who was awarded the dubious honour of the event's head investigator. When the aforementioned order was issued it was immediately questioned by Shcherbina, and his 'subordination' was greeted by a furious General:

> Pilots don't load sand! Their job is to fly aircraft and steer properly. They must be absolutely sure they're right over the reactor, each time. Their hands cannot be shaking. It's out of the question for them to be shovelling sand and dragging bags! - General Antoshkin (Medvedev 1990, 191)

It appears that the General was correct in his insistence that the pilots were exempt from the manual labour of loading the sand, especially when one considers the aviation skills required to complete their mission. Shcherbina's inquiry could have been engendered through his sense of pride, and that of his professional subordinates, or, more likely, by the material and biological repercussions of inhabiting the site of the makeshift helicopter landing pads. Radiation may be invisible, but its atomic structure still obeys the laws of physics, notably in this instance, gravity. Each time a helicopter took off and landed, its blades disrupted the 'dormant' radioactive atoms which had settled upon the ground, resulting in their transportation into the air surrounding the helipad. Each time one of these machines arrived or departed, the levels of radiation within the central square spiked wildly, and anyone present inhaled a huge amount of unstable atoms. Regardless, the orders were followed to the letter by several members of the emergency task force, and the first bombing sorties were underway.

Three of the RBMK's designers took turns accompanying the pilots on these dangerous sorties as they felt better able to guide the pilots's aim. Colonel Nesterov flew the first bombing run; he had already flown the flight path several times before. The first 'phase' of the aerial assault was hopelessly ill-equipped, both in terms of the ammunition they were dropping and also by the means through which they were expelling their cargo from the aircraft. Rather than attaching the bags of sand to the outer shell of the helicopter, the emergency operation loaded them internally, thus requiring their expulsion by hand. This also necessitated the opening of the aircraft's cargo door, which resulted in the levels of radiation inside the craft spiking. Furthermore, the first phase of the operation did not materially alter the MI-8s, and it was only during the second phase that they were retrofitted with lead shielding to prevent (to some degree) the gamma rays penetrating the craft's interiors (Hawkes *et* al 1986; Mould 2000). These sorties were carried out until the evening hours of 27th April, and as the light faded, within the halls of the Government Commission the emergency task force calculated that approximately eighty sacks of sand had been dropped:

> The chairman of the Commission Borys Ievdokymovych Shcherbyna said that this was nothing, a drop in the ocean. It was very little, they needed tonnes.... Throwing sacks out by hand was unproductive and dangerous. And during the night of 27-28 April everyone thought: how can we do this better?... And that night an idea took shape: the load should be hung on the external attachments... On helicopters there are special attachments to suspend loads. You press a button, and it releases the load. - Nikolai Volkozub (Shcherbak 1989, 105)

Volkozub was a senior inspector, airforce pilot, normatively stationed within the Kiev Military District under General Antoshkin's command. He was one of the first aviator actors to arrive after Nesterov and Serebryakov. The above extract delineates his account of the night of the 27th April and the morning hours of the 28th. The nexus between the new agency of the nuclear non-human and the material actions of this group of actors subsequently produced a series of retrofits to the MI-8 helicopters; that is, the physical augmentation of one object due to the needs of another. The consensus within the vast majority of the discussions about the starting date of the aerial battle of Chernobyl is the 28th April, the day that the boron and other materials arrived on site and the helicopters had been successfully retrofitted. It is only within sources telling the personal experiences of actors who were present on the 27th, or interviews with said people, that the relations taking place on this day become visible. Thus, the above account has reassembled the little known 'first phase' of the operations, the unheralded, yet imperatively important test runs which set the foundation for the proceeding sorties.

The morning of 28th April saw the first sorties of the second phase depart from Pripyat and journey the short distance to the NPP. Armed with their new payload and bombing mechanism, the end results of these flights were of much greater significance than the first phase. The pilots did not fly alone, but were aided by an ad hoc ground controller situated near the plant, who was materially assisted by a compass and a stop watch. These two objects were used in tandem to ensure that each sortie dropped its payload at the exact same point, a co-ordinate which was agreed upon during the first phase on the 27th. Later in the afternoon, a 'scouting' helicopter was deployed and it hovered at a higher altitude over the drop zone. This secondary aircraft was tasked with aiding the aim of the bombers and verifying the success of each flight. Helicopters are not typically used for bombing sorties, a type of mission predominantly reserved for planes. Thus, the pilots of these machines were, for want of a better term, far outside their comfort zones during these runs. When the aircraft had reached the designated drop point, the message to release was relayed to the pilot by the ground controller and the scouting helicopter recorded the drop by means of a photographer. This constellation of human actors and objects continuously worked to finesse and improve their tactics during the course of the entire mission. Each time a payload was dropped, the three sources of action correlated their subjective observations and attempted to ascertain if the drop point should be altered, and whether or not the bomb had hit its target. All the while, each of the three groups of actors, one on the ground and two in the air, were being relentlessly bombarded with radiation. On the first day of the mission, 28th April, 93 bombing runs took place (Hawkes *et al* 1988; Hayes & Bojcun 1988; Mould 1988; Lusted 2011). On the second day of the aerial battle for Chernobyl, 186 sorties were successfully flown. This incredible mission continued for a further six days, and, on 3rd May 1986, the reactor had been covered with over five thousands tonnes of material (Hawkes *et al* 1988), and its release of radioactive material into the atmosphere had been partially halted.

At this juncture, a brief account of the unavoidable side effects of the bombing missions must be constructed; that is, the material possibilities which partially manifested themselves within the site of RBMK no4 as a result of the additional mass being placed over the reactor:

> On 28 April, 300 tons were dropped. On 29 April, 740 tons. On 30 April, 1,500 tons; and on 1 May, 1,900 tons. At 7 pm on 1 May, Shcherbina announced that the volume to be dropped would be cut in half. There was a reason to fear that the concrete structures supporting the reactor might not hold and that everything would collapse into the suppression pool, causing a thermal explosion and a massive release of radioactivity. - M Tsvirko (Medvedev 1990, 195)

Tsvirko was the head of Soyuzatomenergostroy and the above extract renders visible one of the material side effects of the aerial bombardment of the nuclear non-human. As previously stated, the lid of the reactor vessel formed the ‘ground floor’ of the facility, but beneath it lay several basement levels. The emergency task force feared that the geo-event had weakened the structural supports of the entire building, and, even when it was not damaged, adding 5,000 tons of extra material onto its frame could result in its collapse. This would have been catastrophic. Luckily, this did not happen, due in part to the type of concrete used within NPPs. The stresses and strains associated with the normative functioning of these facilities requires ‘special’ concrete which is reinforced during the manufacturing process to sustain excessive temperatures and physical loads (Josephson 2000). This ontological necessity of the construction of these power stations is one of the fundamental reasons that the shattered core of RBMK no4 did not free fall into the basement levels of the building. However, its physical robustness still had limits; it had withstood the mass of the helicopter sorties’ cargo, but a new concern arose as a result of the mission, one which constituted the other major side effect of the material blanket hastily cast over the core - excessive heat.

During the course of this mission, the temperature of the nuclear fuel within reactor had been steadily decreasing, but, on 1st May it began to rise once again. The risk of incubating the fuel, which could lead to a re-ignition of the fission reaction was very real, and on this day the emergency task force believed that their worst fears had come to pass. 'The China Syndrome' refers to a belief, that if a fission reactor incurs a meltdown, its super heated fuel would melt through the metal structure of the core and 'burn' vertically into the ground. The use of 'China' is an allegorical means of visualising the power of this transgression. For obvious reasons, this presents a host of complications, none more dangerous than the inevitability of the fuel coming into contact with the nuclear concrete which supports the object of the reactor. Depending on the chemical composition of said concrete, two byproducts can occur. If the concrete is made from silaceous rock, the interaction with the molten fuel will produce steam, which can mutate into explosive hydrogen gas. If the concrete is carbonate based, it melts at lower temperatures and produces explosive carbon monoxide gas (Hamman & Parrott 1987).

Neither of these material eventualities was appealing, and over the four days, the temperature of the core, and its subsequent release of radioactivity, rose to seventy percent of the magnitude experienced at 09.00 AM on 26th April, the time when the 'poisoning effect' had run its course. To counteract this uncontrolled rise in temperature within the core, the emergency task force decided to pump pressurised nitrogen from the facility's compressor station into the space immediately below the stricken nuclear non-human on 2nd May. Over the next four days the temperature rose until 6th May, when, somewhat inexplicably, it began to fall from its 2,000 degrees celsius peak (Mould 1988). This meshing between the aerial mission and the material impacts of their actions 'on the ground' represents a complex and dangerous node of action and physical reaction. As soon as the actors responsible for the emergency operation thought that they might be gaining control of the situation, the nuclear non-human fought back, charging up its super-heated interior as if in defiance of the human actors' tactics. In other words, it routinely represented itself as a quasi-living being, full of agency and potential materialities. Furthermore, this brief account of the side effects of the helicopters' mission renders visible an evolution in the agency of RBMK no4, highlighting that it was not static but in a constant state of flux. It was becoming a hybrid, impacted upon by the influences of the actions it had engendered in the first place. This dance of human action and non-human reaction further strengthens the argument surrounding its status as the most influential actant within the conceptual structure of this piece of research, due to its creation of a perpetually and seemingly endless affective loop.

By 7th May, the mission awarded to the helicopter squadrons was ninety nine percent complete. The vast majority of the pilots had conducted their duties with bravery and efficiency, but there was one last request to be made of the talented aviators by the scientific community of actors tasked with accounting for and understanding the nuclear non-human. In order effectively to plan the meta-operation's next move, the necessity of being able to monitor the materiality of the nuclear non-human in much greater detail presented itself. Evaluating temperature and the types of gaseous release would provide the nuclear physicists and engineers with ample information to ascertain the state of the reactor, and thereby facilitate their planning of its entombment. However, the placement of the equipment necessary to gain these measurements required the physical transgression of the space of the NPP, the immediate lair of RBMK no4. One of the most irradiated sites on the face of the earth. Medvedev (1990) states that during his visit to the NPP, levels of radiation in the immediate vicinity of RBMK no4 were reported to be 2,000 roentgens per hour, and any remnants of fuel within the site reached up to 15,000 roentgens per hour. These scarcely believable levels restricted human movement within this space, thus limiting the options available with regards to the placement of any measuring devices. Therefore, the only conceivable way of placing the thermocouple and gaseous measurement container into the reactor was by means of a helicopter.

Nikolai Volkozub volunteered himself for this, the most dangerous of all of the helicopter missions. As previously stated, the bombing sorties dropped their cargo as quickly as possible, thus minimising the amount of time the pilots spent within the radioactive 'chimney' billowing upwards from the nuclear non-human. However, for this last mission Volkozub had to delicately manoeuvre fragile machinery delicately into place, all at a height which is not conducive to prolonged periods of hovering:

> A helicopter, through its aerodynamic properties, can cover the land either at a height of around ten meters (this is called hovering in the danger zone) or higher than 500 meters. From ten to 200 meters is a prohibited zone... if the helicopter is hovering at a height of up to 200 meters and an engine refuses, the pilot, however high his qualifications, will not land the helicopter, because he won't be able to get the rotor into the autorotation, that is, gliding mode. - Volkozub (Shcherbak 1989, 108)

This illuminating insight into the logic of safe helicopter operations aids understanding of the peril of this mission. Volkozub had to contend with the presence of the radiation/heat *as-well-as* sustained hovering at an altitude which is essentially banned. On the afternoon/evening of 7th May, the pilot and the engineers of the emergency task force formulated a plan which involved the attachment of a long steel cable, weighing 200 kg, to the underside of his aircraft, and the thermocouple was to be suspended at the far end of it. The 8th April was spent practising the manoeuvre and laying the necessary connecting cables needed to extract the data from the device from Pripyat to the site of RBMK no4. The 9th April marked the day of the live operations. Volkozub approached the site of the reactor at a height of 350m, and, with the aid of his flight assistant and scouting helicopter, took the temperature measurements:

> Evgenii Petrovich Riazantsev was himself looking through the hatch and telling me where I was with gestures: 'Over the reactor'. We made temperature measurements at a height of fifty meters, forty, twenty and in the reactor itself.... Six minutes and twenty seconds had passed from the moment we had been hovering. It had seemed an eternity. - Volkozub (Shcherbak 1989, 112)

On 10th April, Volkozub repeated these heroics to place the gaseous measuring equipment, and once again on 12th April to deploy the thermocouple one last time - three missions hovering above the jaws of an out of control nuclear reactor. In total, Volkozub spent nineteen minutes and forty seconds hovering above the ruins of RBMK no4. He does not state in his account of these missions the amount of radiation to which he was exposed, but conservative estimates would be in the region of 200 to 300 roentgens (Ushakov and Soldatov 1993).

Figure 4.11: vehicle graveyard in the Zone (source: Solo East Company website)

This final node of action represents the closing act of the aerial battle of Chernobyl, the most impressive, dangerous and sparsely documented climax of a series of actions which claimed the lives of several of the pilots. The construction of this account has highlighted that the material side effects of these sorties – the physical impacts on the nuclear non-human – could have resulted in more catastrophic explosions, but there was simply no alternative in the week following the geo-event. Action had to be taken to quell the vast release of radioactive material pouring upwardly from the shattered core and an aerial assault was the only feasible way to achieve this end. Today, within the world of the Chernobyl NPP, one of the most popular, and potentially dangerous, extreme tourist 'attractions' is the vehicle graveyard (figure 4.11), the resting place for the hundreds of industrial, military and civilian machines used in the clean up operation. The use of these objects in the immediate aftermath of the geo-event has rendered them too irradiated ever to leave the Zone of Alienation, and now they sit dormant and forgotten, patiently counting the centuries needed for their atomic coating to decay away. This is the fate of the fleet of helicopters used within the aforementioned arial battle, a depressing and ultimately thankless memorial to the non-humans whose importance during the stabilisation of the post geo-event reality cannot be understated. Once again, without the synergy between these objects and their human actors, the Chernobyl disaster could have been a lot worse.

4.4: From Atomgrad to ghost town: the evacuation of Pripyat and the creation of the Zone of Alienation

Figure 4.12: Pripyat sign (source: researcher's own photograph 2015)

At this juncture, analysis will depart from the object of RBMK no4 and focus upon another repercussion of the explosion on 26th April 1986; that is, the evacuation of Pripyat. In order to account for this forced migration of human actors, analysis must return to the days immediately following the geo-event. The reasoning behind the non-linear chronology of this account is rooted in the theoretical placement of the nuclear non-human as the most influential and powerful actor within this research project. All that has been covered thus far has detailed the efforts of the constellated actors tasked with taming the object itself; that is, the actions spawned by the object's agency, consequently being orientated towards its ontological structure. The evacuation of Pripyat represents one of the largest nodes of actions associated with the post geo-event stabilisation effort, and it featured the physical relocation of tens of thousands of people in a matter of hours. These material transgressions had no impact back upon RBMK no4; the sole purpose of this movement of human actors away from the epicentre of the geo-event was for their self preservation. Thus, conceptually speaking, the evacuation of Pripyat represents a one way node of action, one which did not form a continuous cause-effect loop with the nuclear non-human. In this instance, the agency of the object 'barked' and a vast conglomerate of actors jumped to its command, never to return to its sphere of influence again. What follows is a brief account of the process which resulted in the evacuation of Pripyat, supplemented by a delineation of how the entire city population of a city was removed from its urban environment in a matter of hours. This process began at 9.00 pm on 26th April.

During the evening of the 26th the emergency task force concluded that Pripyat had to be evacuated. Due to a change in the wind patterns, the radioactive plume billowing outwardly from the reactor had changed direction, and was now heading in a north westerly direction, placing the atomic city directly in the path of the unstable atoms encased within the plume. General Berdov was placed in charge of the operation, and he made the decision to evacuate the town, together with the other members of the emergency task force, in light of receiving measurements of the ground levels of radiation within the urban environment of Pripyat. By 9.00pm, said level was one hundred thousand times more than the natural background radiation (Hayes & Bojcun 1988; Jensen 1994), which represented a massive and untenable risk to the human population of the city. The evacuation decision was kept completely secret from the general population, and all they were told was to stay indoors and keep the windows of their flats sealed (Hamman & Parrott 1987). The plan was to move the citizens on the morning of the 27th, however, the logistics of sourcing and relocating the means to transport close to 50,000 people put an end to this timescale. Thus, during the midnight hours of the 27th, a frantic search began to locate the necessary vehicles and to summon them to Pripyat:

> By 3am, it became apparent that a morning evacuation would be impossible, both organisationally and technically. The public had to be warned. It was then decided to

> hold a meeting in the morning of representatives of all the enterprises and organisations in the town, so as to explain the evacuation in detail. - V Shishkin. (Medvedev 1990, 183)

The fleet of buses originated in Kiev and soon after midnight they began the journey to Pripyat in a procession over twelve miles long. One thousand two hundred and sixteen buses were used within the mass evacuation of Pripyat; and, upon their arrival in the world of the Chernobyl NPP, they spent the night just north of the village of Chernobyl, patiently waiting within the irradiated landscape for the call to take the final leg of the journey to Pripyat. Early in the morning of the 27th, a city wide broadcast came over the city's speaker system warning the general population of their evacuation later in the day:

> Comrades, in connection with the accident at the Chernobyl Nuclear Power Station we announce the evacuation of the town. Have your papers, indispensable things and, if possible, rations for three days, with you. The evacuation will begin at 14.00 hours. (Schcherbak 1989, 64)

This message was broadcast four times and everyone within the city was led to believe that their removal from their homes would last three days. Thus, the residents planned and prepared for this time period. At 2.00pm, the convoy of buses arrived at the doors of the modernist inspired flats within the city's urban environment.

Figure 4.13: the buses used during the evacuation (source: Kostin 2006)

Figure 4.13 show part of the legion of buses and some citizens during the evacuation, and it is one of the few images that exists. As this operation was commanded by an actor from the military of the Soviet Union, the men who physically orchestrated the resident removal from their homes were soldiers.

> Buses rolled up outside each apartment building at exactly 2 P.M. We had been warned already over the radio to dress lightly and take as little as possible with us, as we would be returning within three days. I found myself wondering what this really meant, because if we had taken lots of things even 5,000 buses would not have been enough. - G Petrov (Medvedev 1990, 187)

Once a bus had been filled it drove to join the end of the procession, and subsequently on to the reception centres, 50 km south west in Polesskoe (Jensen 1994). The entire town was evacuated in under three hours, with several sources stating that the total time was two hours and forty five minutes (Hawkes *et al* 1986; Mould 1988). The military command of the evacuation engendered this impressive completion timescale, and its evacuation of the city was one of the first instances when the general public was forced to 'act' in light of the geo-event. In hindsight, the clinical manner in which they were informed and moved, devoid of the frenetic panic encountered by the actors in charge of the emergency operation, resulted in calm and purposeful results. In other words, ignorance is bliss. From inception to execution, the entire operation was run with a militaristic attention to detail, and this calculated aura subsequently calmed the citizens during an extraordinary situation. Other than a few minor 'arguments' with the soldiers over their forced migration, the general population of the city accepted this unavoidable relocation and, as evident in the time it took to evacuate the city, swiftly carried out the orders of the USSR.

The departure of the last remaining 'civilians' from the immediate area surrounding the NPP allowed these militarily empowered actors to forge ahead with a spatialising form of action, one which, as the material effects of the geo-event rippled through the landscape, would only increase in scale, resulting in further impacts upon the neighbouring population centres. The 'Zone of Alienation', or 'Zone of Exclusion', became a thirty kilometre bounded area deemed too irradiated for human activity. One must gain Governmental permission to access its boundaries, and the town of Pripyat, and the village of Chernobyl are the two most notable settlements within its restrictive confines.

Figure 4.14: Map of the Zone's spatial boundary (source: chernobyl-tour.com 2010)

Figure 4.14 delineates the spatial boundaries of the Zone as it stands today. However, its creation featured two phases, one initiated on 28th April, the day after the evacuation, and one starting on 2nd May. The first phase featured a 10 km exclusion zone, one which incorporated the site of the NPP and the town of Pripyat, and the second phase produced the limits of the zone as they are today (Jensen 1994). The order to initiate the second phase came directly from Moscow (Hawkes *et al* 1986) and it saw further evacuation, most notably within the village of Chernobyl. No accountable material exists from this second evacuation; this may be a result of the movement of the emergency task force's ad hoc headquarters to the village of Chernobyl on 29th April (Medvedev 1990), thus casting a veil of Soviet secrecy over the settlement. Regardless, by 6th May 1986, approximately one hundred thousand people had been permanently removed from the landscape of the Chernobyl NPP, and its transformation from its pre- to post geo-event demographical makeup was complete.

The evacuation of Pripyat and the epistemological creation of the Zone of Alienation were reinforced by ontological realities, notably, a complex network of military checkpoints, radiation warning signs, and a boundary fence. The removal of the vast proportion of human actors from the space was an obvious result of RBMK no4's new agency, and the entire process produced a unique series of actions on a host of different levels. The 'official' planning and execution of the evacuation has not been well documented, but the hybrid agency of the actors of the emergency task force played out in a vividly accountable and impressively efficient manner across the landscape of Pripyat, and the village of Chernobyl. Furthermore, the *visible* adaptation of the physical environment engendered an 'observable by human senses' means of identifying the presence of radioactive fallout, *as-well-as* creating the material boundaries of the Zone of Alienation. Today, Pripyat is a shadow of its former glory, a broken and empty urban landscape, devoid of human relations and slowly being eroded by the agents of time and nature. It has become one of the most recognisable images of the Chernobyl disaster, due to its uniquely desolate cityscape. Its empty streets and ruined apartment buildings serve as a reminder of the influence of RBMK no4 and the power of its agency over its surrounding material landscape/human actors. Pripyat was once the model Soviet city, premiered as far away as Moscow. Now, in the post geo-event reality, the only group of people who hold it in high regard are the people who go places/spaces that they are not supposed to go; that is, it represents the Mecca of Urban Explorers (as explained in chapter 1) – a stark contrast to the proud Atomograd status that it once enjoyed.

Figure 4.15: Landscape view of the southern section of Pripyat (source: researcher's own photograph 2015)

4.5 The entombment of the nuclear non-human and the environmental clean up: the final scene of the stabilisation effort

Analysis will now return to the object of RBMK no4 and resume a linear chronology. Outwith the account of the evacuation of Pripyat, all that has been assessed thus far has detailed the actions towards taming the nuclear non-human; in essence, stabilising its ontological make up post geo-event. In the days following the completion of the aerial assault on the stricken reactor, the interior of the object cooled and calmed to a point where the emergency task force could begin to plan for the next mammoth challenge that had to be met - the quasi-permanent entombment of RBMK no4. The construction project required to erect the structure over the ruined reactor is an engineering marvel of the modern world, and its vast steel walls and retrofitted demeanour have subsequently become the visual representation of the once little known NPP in Northern Ukraine. Officially named the 'Shelter Site of Power Unit 4 of Chernobyl NPP', colloquially referred to as 'the Sarcophagus', this huge structure was allocated the imperative task of eliminating the material consequences streaming from the geo-event. Thus, in light of its complexity, scale, influence upon the political climate of the era, and its responsibility over the fate of literally millions of people, the speed with which it was designed and constructed is a testimony to the bravery and professionalism of the actors who contributed to the project. Prior to accounting for the process which engendered the steel tomb, an introduction on said actors must be provided, for without their actions, the object of the 'Sarcophagus' would never have been realised.

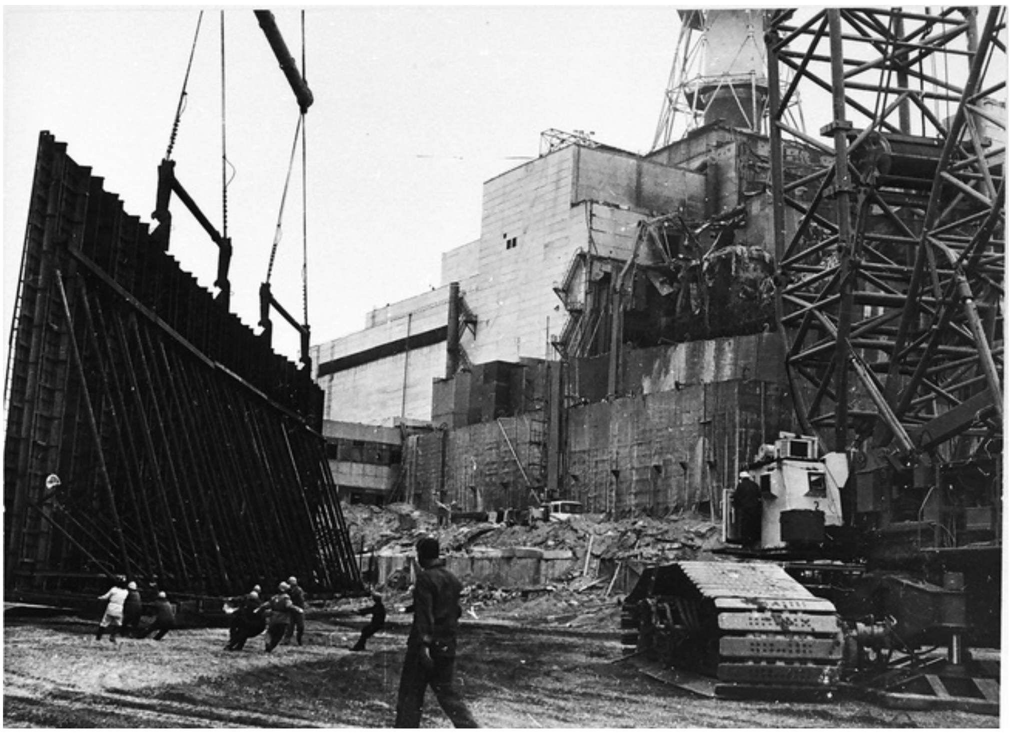

Figure 4.16: Construction work on the Sarcophagus (source: Kostin 2006)

Figure 4.16 portrays a group of actors attempting to erect a section of the Sarcophagus, and the label awarded to this vast army of workers, forcefully drafted into the clean-up operation, was 'liquidators'. The logic behind this naming was derived from the Russian verb to eliminate, that is, the elimination of the consequences of an accident (Belyakov *et al* 2000). During the early period of the post geo-event stabilisation effort, the Soviet officials believed that the material repercussions of the disaster would be eliminated in a relatively short period. This factor alone discloses their lack of comprehensive understanding of the physicality of radioactive fallout, although this belief was rapidly dispelled through the brutal and life altering effects that this invisible material began to inflict upon all who transgressed the Zone of Alienation. The clean-up operation was doomed to fail its original objective, the task to which the mantra of 'liquidator' owed its existence; that is, 'eliminating' the consequences of the disaster was ontologically impossible to achieve. Therefore, the mission shifted its parameters and evolved into a form of damage limitation, a movement from eradication to the reduction of the impact of RBMK no4, but the nomenclature remained.

There are various estimates about the total number of liquidators forcefully drafted into the site of the NPP, but the OECD Nuclear Energy Agency report (1995) on the radiological effect upon these actors states that their numbers totalled up to 800,000. The ambiguous label of liquidator incorporated a diverse demographical make up: from truck drivers, to concrete specialists, to construction workers, to simple labourers; no matter what duty, they all fell under the aforementioned mantra. Only the soldiers who braved the immensely irradiated rooftop to rid it of graphite moderator were provided a divergent description, that of 'bio-robots', a name which does not really reflect the immense dangers to which they were subjected during these missions. The environmental clean-up operation of the new world of the NPP continued until 1989, but the construction of the Sarcophagus was completed by November 1986. This is the period of greatest relevance to this account: the epoch of the stabilisation effort, the material entombment of RBMK no4, and the re-installation of the new synthesis of the post geo-event world. The first visibly accountable trace appeared on 11th May, shortly after the completion of the aerial battle for Chernobyl:

> Until now, the possibility of a catastrophe really did exist: a great quantity of fuel and graphite of the reactor was in an incandescent state. Now this is not the case. - Evgeny Velikhov, Scientific Leader of FSU. (Hawkes *et al*, 1986, 180)

This statement, uttered by an extremely influential actor within the FSU, represents an articulate and purposeful mediation of the disaster. He made it clear that the nuclear non-human was now under control and highlighted that the risk of a 'catastrophe' was now diminished. The paradoxical irony of this statement is plain to see, as the rest of the world would readily class the series of events which resulted in the explosion on 26th April 1986 as a 'catastrophe'. Regardless of this instance of mediated political subterfuge, this date represents the start of the Shelter project, the point in time when RBMK no4's agency experienced a further mutation and sparked a new series of emergent actions tasked with catering for its evolving physicality. By the middle of May 1986 the emergency task force, in conjunction with a Governmental committee, made a decision upon the entombment of RBMK no4, one which would see a short-term containment structure being erected around the ruined reactor. As a brief aside, the 'short-term' containment has yet to be replaced today.

The purpose of this physical barrier between the radioactive interior of the RBMK (and its reactor hall) was to enclose said fallout and restrict its movement into the landscape. Furthermore, it was hoped that this separation would allow the radioactive substances within to decay to a level where further decontamination of the site could commence (Kurnosov *et al* 1988). On 28th May 1986, the meta level command and responsibility of the Shelter Site of Power Unit 4 of Chernobyl NPP project was 'outsourced' to the Ministry of Medium Machine Building of the USSR, and the design of the containment structure was entrusted to the VNIPIET research institute and the Scientific supervision of the process to the Kurchatov Institute of Atomic Energy (Kupny 1996). Thus, the network surrounding the station expanded to incorporate a heterogenous range of institutions and a subsequent plethora of informed and influential actors. Unfortunately, personal accounts, or interviews with the actors implicit within these institutions, and the project in general, do not exist. The personal experiences which have been deployed throughout my account above end by the middle of May; and, as the Shelter project incorporated 'distant' actors, that is, men who were neither directly employed by the NPP nor drafted into its site immediately after the geo-event, it appears that they might have been bound to silence through Soviet secrecy legislation (Lusted 2011).

Due to the extraordinary situation, and the less than ideal construction conditions, no less than eighteen design variants were developed (Haynes & Bojcun 1988). The vast majority of these designs required significant economic investment in construction materials, a huge labour force, and the timescale associated with these designs was between one-and-a-half years to two years (Kurnosov *et al* 1988). The finance and human power was a logistical unavoidability, but the time for completion was completely untenable. Leaving the nuclear non-human open to the elements during two winters could result in its radioactive interior being subsumed into the water table and, consequently, directly into the bodies of the surrounding population, most notably, in the city of Kiev. The key difference between the rejected design variants and the one which was chosen becomes visible when one accounts for the supporting structures that each sought to utilise. The rejected proposals required an independent foundational platform to build upon, which would take time, money and cost human lives due to the extended exposure to radiation that the liquidators would have to endure. The design variant which was chosen utilised the remaining structure of the reactor building as its foundational anchor, in that the steel outer casing would be attached to the shattered building, thus slashing the completion timescale. There is no accountable record of how the designers and engineers attained the necessary information to assess the structural rigidity of the partially destroyed reactor building. It is safe to assume that the decision to build on top of a weakened building was extremely risky, especially when one considers the importance of the retrofitted object. However, the Sarcophagus has stood for 30 years and its designed window of operation was to last for only five (Berthold *et al* 2002). Hence, regardless of the lack of the aforementioned accountable information, the fact that this retrofitted structure has withstood a period over five times its design specification is a testimony to the actions of its designers.

The chosen design was completed at the start of August, but it was continuously altered throughout the construction programme, due to the non standardised environment and foundational support. Akin to the nuclear non-human, the Sarcophagus was designed to cover as much as possible, and everything about its ontological make-up was a dizzying array of mammoth statistics. Over 300,000 cubic metres of concrete were laid, while in excess of 7,000 tons of steel structures had to be manufactured, transported to the site, then erected. The 200 m tall walls had to be filled with concrete and rigidified by thousands of reinforcing bars. Furthermore, the ceiling had to be craned into position, piece by piece, with an insistence upon total accuracy (Kupny 1996). The general design ethos of the Sarcophagus revolved around not only sealing the nuclear non-human from the environment, but also creating internal barriers tasked with safeguarding the still functioning units 1, 2 and 3. The Chernobyl NPP was fundamentally important to the Ukrainian national electricity grid, and, due to the geo event, its meta output had been quartered. This reduction represented a huge logistical problem, because, without the still functioning units, there would have been massive energy shortfalls in Ukraine. A massive concrete dividing wall was therefore constructed between unit 3 and the destroyed unit 4 – figure 4.17 shows this wall. This new structure reached the roof and it was supplemented by a firewall to safeguard against any unforeseen incidents within the destroyed reactor hall. As unit 3 was the sister unit of RBMK no4, it had been affected the most by the geo-event, but units 1 and 2 were essentially unharmed due to their placement at the opposite end of the building. Thus, these two reactors were the first two to be back online, and an airtight metal wall was constructed to separate unit 2 from unit 3. This barrier sealed off any 'internal' radioactive transgressions, and facilitated the return to normal functions of units 1 and 2 (Kurnosov *et al* 1988).

Figure 4.17: Corridor that leads to makeshift wall, separating unit 3 from the destroyed unit 4 (source: Researcher's own photograph 2015)

The assembly of the steel outer casing of the Sarcophagus was carried out from three sides, and, as no one side of the original building was unaffected by the explosion, each entailed a delicate and conceptually autonomous process (Belyaev 1993). The west wall of the reactor building was damaged, but it retained a notable amount of structural integrity. Regardless, it was reinforced by a massive steel corset both inside and outside the building, and the interior of this new appendage was subsequently filled with concrete to further strengthen its reinforcing properties. Due to the excessive damage to the north side of the building, an entirely new walling structure had to be built, one which was also filled internally by ferroconcrete. This process was repeated on the southern facing wall, and a huge load bearing beam, weighing 146 tons (Kurnosov *et al* 1988), was placed atop this new structure to form the keystone of the roofing elements. The roof itself was attached to the north and south walls, and it comprised huge metal shields, placed individually then joined together through a series of locking nuts. This account of the material properties of the Sarcophagus do not do the process justice. There has never been a construction project like it, and, hopefully, there will never be the need for one again. Figures 4.18 and 4.19 depict two stages of the construction process, the first delineating the early stage and the second visualising the roofing elements being placed upon the aforementioned load bearing beam on the southern facing wall. These illustrate the discursive account, ocularly rendering visible the materiality of the structure and the ontological reality engendered by the agency of the nuclear non-human.

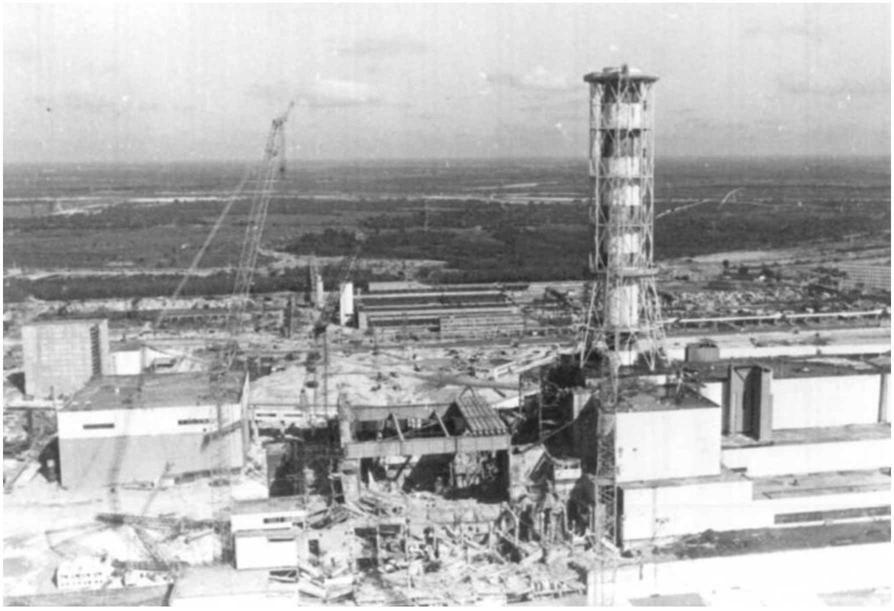

Figure 4.18: Early construction stage of the sarcophagus (source: Kostin 2006)

Figure 4.19: Roofing stage of the construction of the Sarcophagus (source: Kostin 2006)

These images offer a visual 'description' of the state of the building during the retrofitting of its shelter. A mass of twisted metal and shattered concrete is seemingly all that remains of the original structure which housed the nuclear non-human. The second image was taken towards the end of the process, and the devastation of the geo-event is still clear to see. The scale of the new object is also clear to see, and the sheer amount of materials that went into its construction was beginning to take its toll upon the Soviet infrastructure.

The production of these raw materials put the Soviet industrial sector under a huge amount of pressure, and towards the end of the process the strain began to have a detrimental impact upon the timescale. The final entombment of the nuclear non-human occurred in mid-November 1986 (Mould 1988), roughly one month behind schedule. Visually, steel seemingly represents the majority of the mass of the Sarcophagus; when one views its exterior, this component dominates the object but making an assumption of this nature betrays the ontological make-up of the shelter. The manufacturing and construction of the steel ran smoothly and efficiently. It was the staggering demand for concrete that delayed the completion of it. As stated above, over 300,000 cubic metres of concrete were used, and the bottleneck in its production was a serious worry for the institutions given command over the Sarcophagus's construction. The steel outer casing carries the aesthetics of the Shelter, but the oceans of concrete form the dominant part of its total mass and the foundations to which the steel was attached. Regardless, the delay of a month still resulted in the nuclear non-human being entombed before winter, and the project was deemed a massive success. In roughly four months, this totally unique structure was planned and built, an impressive feature when one considers the other, invisible, and omnipresent variable with which it had constantly to contend.

The existence of radioactive fallout presented a massive issue for this huge construction project. The levels within the reactor hall averaged 600 roentgens per hour, and maxed out at 2,400 roentgens per hour (Kurnosov *et al* 1988). This space had to be occupied to construct the inner support structure for the west facing wall, and during the erection of the segregating wall between the unit 3 and 4. Dependent on the exposure levels, the army of liquidators worked in very short shifts, typically two hours, but when transgressing the most irradiated spaces of the NPP, these shifts were shortened to under an hour (Belyakov *et al* 2000).

4.6 Conclusion

This is a fitting way to conclude this account, with the actors who braved these conditions to build the Shelter, and also to revert thoughts back to the actors implicit within the other sections of this account. The helicopter pilots, firemen, army generals, scientists, engineers, soldiers and construction workers were all forced to act by the agency of RBMK no4, and they did so in the knowledge that they were likely shortening their lives due to their exposure to unstable atoms. The completion of the Sarcophagus signalled the reinstallation of stability to the world of the Chernobyl NPP, the moment when the agency of the nuclear non-human was almost completely tamed and after it experienced its final mutation, one which denied it the powerful influence that it had 'enjoyed' for the previous seven months. Today, RBMK no4 is still a powerful actor, still profoundly influencing human actors and a host of societal domains. Arguably, its 'reach' is wider as its ontological needs have to be met by the intentional community; however the actions it spawns are not as direct, purposeful or heroic as they were in 1986. This chapter has rendered visible the heterogenous melee of actions tasked with catering for the object in the immediacy of the geo-event, some well known, other less so. Outwith the evacuation of Pripyat, the actions of these human actors formed an intriguing loop with the shattered reactor: a series of cause, action, effect, and reaction relations; a material dance between an immeasurably powerful nuclear non-human and its fleshy human puppets, all performed under the invisible spotlight of radioactive fallout. Not long after the geo-event, units 1 and 2 of the facility were charged up and put into service once again, followed later by RBMK no4's sister unit 3. The stabilisation effort, the material implementation of a new transcendental in the form of the Sarcophagus, facilitated elements of the pre-geo event world to return to the fray. However, as a RBMK reactor had catastrophically malfunctioned, the fear that this type of accident could recur began to manifest itself. The Chernobyl facility was only one of several other Soviet designed NPPs which operated the RBMK reactor. This emergent agency, and subsequent node of action, shall be covered within the concluding chapter, as the programme tasked with evaluating the risk of the RBMK fleet represents a fitting instance with which to cap this research. For now, analytical attention will turn to the material transportation of RBMK no4's radioactive innards across the landscapes of Europe, seeking to provide a very literal answer about how the nuclear non-human travelled.

"Chernobyl was, is and will always be one of Ukraine biggest problems." Oleh Andreev

Chapter 5

Rendering visible the invisible: the clandestine world of radiation and the atmosphere.

> We travel together, passengers on a little spaceship, dependent on its vulnerable reserves of air and soil, all committed, for our safety and its security and peace. Preserved from annihilation only by the care, the work and the love we give our fragile craft. (Stevenson 1965)

This chapter seeks to account for the travels of charged materiality from RBMK no4; that is, the physical transportation of radioactive material from the stricken reactor across the landscapes of Europe, and a selection of the actions spawned by this transgression. The key complication for the work conducted at the time of the disaster, tasked with registering the aforementioned spread, and by proxy, for this piece of research, is the fact that both radiation and its vehicle of transportation, *the atmosphere*, are invisible. In order to render these agents visible, a series of practices, developed across decades, and in some cases centuries, must be enacted, and a host of specifically designed objects must be used to facilitate these materially affective relations of making visible.

The empirical core of this chapter is the European Commission's (1998) *Atlas of Caesium Deposition on Europe after the Chernobyl Accident,* an impressively constructed tome, one which correlates the research of several prominent environmental physicists from a range of European countries, that delineates the dispersal of caesium-137 across Europe. By means of an empirically analytical journey, this chapter will conclude with a Latourian discussion, asking whether this internationally constructed *Atlas* represents either a Latourian oligopticon or panorama - a decision which can only be reached through the reassembling of its composite parts and network. This process, for a social scientist, treads what might appear to be exclusionary and sterile discourses of the hard sciences, particularly that of atomic physics. Thus, in order to provide a base of situated knowledge with regards to this body of scientific logic and the entity of radiation, a condensed history of the development of atomic theory/physics will be provided, one which encompasses a small selection of key actors and their impact upon the development of the science which renders visible the invisible and utilises it for destruction and electricity.

This initial account will be supplemented by a sustained exploration of the ontological entity of ionising radiation, one which takes seriously its impacts upon biological organisms and, through an ANT account, will connect scientific/medical concepts to a real world node of actions engendered by RBMK no4. Furthermore, this two part process is tasked with providing a means through which this research can 'render visible' the invisible agent of radiation, firstly through its effects on biological organisms, and secondly through the practices of environmental physicists. The overarching purpose is to attune the social science sensibilities of this research with the key developments which culminated in commercial utilisation of 'the atom', its unavoidable side effect of radiation, and the practices deployed to gather the data encased within the *Atlas*.

5.1 The journey of the concept of the atom across the millennia.

The material world, or at least the version of it that is perceivable by the sensorial equipment of the human body, is compositionally constructed by a vast combination of objects. These range from the mammoth products of state led civil engineering works to the mundane utilities of everyday life. Some objects are manufactured from one piece of material, no joins or seals, just a uniform structure, and others are the meta form of several interwoven parts, the sum total of a series of specifically designed 'minor' objects tasked with materially co-operating to engender something larger. Regardless of their 'meta' ontological composition, every object within the material realm renders itself visible to human senses - we can feel, smell, touch, taste and see them. This perceivability, outwith the philosophical baggage surrounding their status, facilitates the ability to research them; that is, the incorporation of objects into any number of analytical endeavours. Taken at this level of existence, objects freely open themselves to such enquiries, but, akin to the aforementioned 'jigsaw' composition of certain examples, there exists another scale, another realm, inhabited by incomprehensibly small entities which represent the most fundamental building blocks of the material world. Thus, every object, be it massive or tiny, complex or simplistic, is the end product of a bonding together of billions of minuscule material ingredients.

This 'invisible' realm is, ultimately, that of the atomic, the birthplace and bedrock of sensorially recognisable matter (McCormack 2007). Every substance in the universe, be it gaseous, liquid, or solid, is composed of a numerically vast interconnected network of atoms. This has always been the case, and, unless the universe experiences a paradigm shift with regards to its ontological make up, it will always be the case. However, humanity's knowledge of this minute field of existence is fleeting, in that our ability to identify scientifically its presence and, by proxy, render visible its intricacies, is a relatively contemporary one. The idea of the atom, that is, the philosophical negotiations surrounding its existence, dates back to Ancient Greece. The term atom was first penned by Leukippos and the two general assumptions made in this period stated that matter is composed of extremely small corpuscles, and that their structure is infinitely hard, bordering on unbreakable (Justi & Gilbert, 2000).

In the period after the Greek interest in the make-up of matter, a millennium of speculative research was conducted upon this subject. This endeavour ranged from Aristotle's critique of the ancient model of atomic theory in 200 A.D, through to the works of the eleventh century, when Bacon and Magnus used the teaching of Aristotle as a foundation to probe further into the invisible realm of the atomic (Partington 1939). An interesting facet of this historical development is that the genealogy of contemporary atomic theory originated within the discipline of chemistry, and not physics. This is evident in the works of the first actor of significance within the network of atomic science, John Dalton. He was one of the first chemists (later a physicist) to create a theory which sought to explain the principles of the atomic realm. His work was influenced by the logic of the early Greek philosophers, and the origins of his theory are historically and personally ambiguous, with several events being proclaimed as the incisive moment of articulation (Nash 1956). Regardless, in 1808 he published a book, *A New System of Chemical Philosophy,* which detailed the sum total of his work thus far.

Akin to the Greek notions, Dalton summarised that matter is comprised of minute entities called atoms; that the atoms within any given elements will be of identical size and mass; what within chemical reactions atoms are combined, separated or rearranged; and that the bond which unites the structure of atoms is unbreakable. In other words, atoms cannot be divided, created, fused or destroyed (Dalton 1808). Furthermore, within his *New System,* Dalton actively calculated the atomic weight of a section of elements and, crucially, articulated/invented symbols to represent atoms and molecules - a system which, in a notably different and simplified guise, is still utilised today. In essence, Dalton began the building process to construct the periodic table, the drive to identify, distinguish and chart the differences between elements by their atomic structure (Melsen 2004). Outwith the creation of an initial framework of an atomic theory, the important development here was the movement from philosophical negotiations into the area of semi-stringent scientific testing; that is, the use of purposefully designed methods, experiments, and objects to probe at the atomic realm.

Dalton's atomic theory was in no way perfect. In fact, it had as many detractors as proponents, primarily due to the fact that it did not predicate itself upon an arbitrary set of laws. Granted the above mentioned 'tenets' could be classed as such, but in the hard sciences regimented and universally tested/applicable laws far outweigh the assumptions based on a series of non-repeated experiments (Partington 1939; Justi & Gilbert 2000; Melsen 2004). Rather than chart the journey through the entirety of the nineteenth century, accounting for the scientists who built upon the framework provided by Dalton, this historical account will refocus its gaze upon the final decade of the period and the landmark discoveries of Roentgen and Becquerel, two of the founding fathers of the nuclear age/physics. On 8th November 1895, Wilhelm Roentgen discovered that certain chemicals glowed fluorescent when exposed to cathode rays. These elements were the anticathode within a Crookes glass tube, a vacuum sealed device which channeled electrons between its positive and negatively charged ends (Bertin 1978). This fluorescent glow was not a result of electrons, but instead an entirely new form of what was later referred to as radiation - Roentgen named these new and strange rays, X-rays (Kriz 1995).

Crucially, the discovery of the rays' immunity to the electromagnetic forces within the tube was groundbreaking, but the full extent was not fully realised until Henri Becquerel, almost by chance, stumbled upon the phenomenon of radioactivity one year later. He observed that plates wrapped in photographic material were blackened when placed near certain luminescent minerals. In essence, an invisible and, at the time, totally unexplained phenomenon was interacting with this photographic material. The element emitting these strange rays was uranium salts (Martins 1997), and, as the science here subsequently spawned the nuclear industry, this element would play an integral role in its development. Becquerel's discovery arguably marks the inceptive moment in spacetime when the movement from classical physics to the modern/contemporary iteration of physics was initiated. Prior to the discovery of radiation, the disciple of physics knew of, and could prove, the existence of two fundamental interactions: gravity and electromagnetism (Wong 1998). As Roentgen's x-rays and Becquerel's radiation were not physically or materially impacted by these two core tenets of the discipline, an entirely new phenomenon had to be explored and accounted for.

Granted, all three of these interactions are invisible to the human senses, but of key relevance to this piece of research is the fact that radiation is ontologically material in nature. Gravity and electromagnetism are forces: they may be produced by objects, be it a planet or a magnet, but their effects on matter are not the result of transgressing atoms. In other words, these fundamental forces *affect* matter/atoms, but they are not ontologically comprised by them. We may not be able to register the presence of radiation without the aid of a host of measuring objects, but that should not exclude it from any materially orientated research/theorisations. Radiation is simply unstable atoms, and these renegade entities *affect* the stable atoms with which they come in contact. Thus, when Becquerel placed his uranium salt beside the photographic paper, the radiation/unstable atoms emitting from the uranium were what caused the physical change. This logic is retrofitted to Becquerel's discovery, but in reality it took a further three years of research until Pierre and Marie Curie theorised that radioactive particles cause the systematic breakdown of stable atoms with which they come in contact. This conclusion was reached in 1898 through their experiments with polonium and radium, and their subsequent successful separation, a feat once believed to be impossible (Belloni 2011). In essence, these two human actors were the first to create an artificial, radioactive element by means of nuclear physics: that is, making a transuranic element.

At this point this condensed history will fast forward seven years, passing in its wake J.J Thomson's discovery of electrons (Falconer 1987) and Max Planck's work which would later be known as quantum theory (Klein 1961), and arrive in 1905 with one of the most influential actors within the network of the atomic sciences. Albert Einstein is arguably the most well known physicist who has ever lived. Together with Pythagoras' theorem concerning triangles and Newton's law of dynamics, his equation which unites the entities of matter and energy is arguably the most famous 'natural law' ever calculated and published (Frischkent *et al* 1998).

The reason for accounting for Einstein's work is due to its importance to the process and development of nuclear fission, the means through which nuclear power stations, and the early nuclear weapons, derive their power. Einstein stated within his theory of special relativity that there is a fundamental connection between energy and matter, in that the two are equivalent. Thus, inert matter contains huge amounts of latent energy, and if certain structural/fundamental building blocks are removed, this pent up energy can be released - energy can be created and matter destroyed. This general principle of relativity represents the core idea at the centre of the science which would develop into the nuclear industry (Murray 2001). However, in 1905, it was nothing more than a theory. To understand its significance, this historical account of the atom must proceed to 1938 and into the cauldron of the Second World War.

No one, including Einstein, had managed actively to put this theory into practice before 1938, although, the revolutionary works of Lise Meitner, Otto Hahn and Fritz Strassmann in Berlin and

Enrico Fermi in Rome changed this. These teams were experimenting with uranium-238 and, by means of neutron bombardment, discovered that the nuclei within the uranium atoms, if hit at the correct speed, would split apart and release a huge amount of energy, in accordance with Einstein's theory (Anderson 1997). Thus, if a large enough mass of uranium-238 was present, this process could ignite a chain reaction within the element, a self sustaining 'fissioning' of one atom to another. Scientific reasoning shaped and characterised the following eighty years of human existence, the first point in history when the invisible realm of the atomic had been rendered visible and its material appropriation begun. As with many scientific discoveries, if it is useful to the military in any way, this sphere of society will utilise it first and in war time this fact reigns supreme. So much so, that on 2nd August, 1939, Einstein, fearful of the material ramifications of his theory of special relativity, composed a letter to President Roosevelt, detailing the impact and danger of this new epoch of science. This letter represents the inception of the nuclear age, the event which would, over the decades, fundamentally change our society, and commence the era characterised by the invisible realm of the atom. It reads:

> Sir:
>
> Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:
>
> In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large qualities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.
>
> This new phenomenon would also lead to the constitution of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in port, might very well destroy the whole port together with some of the surrounding territory.
>
> In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an unofficial capacity. His task might comprise the following:
>
> a) to approach Government Departments, keep them informed to the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States.
> b) to speed up the experimental work, which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required,

through contracts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industry laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State is attached to the Kaiser-Wilhelm-Institute in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
Albert Einstein. (in Stoff et al, 1991, 18-19)

The importance of this document cannot be stressed enough - it reflects the agency of one of humanity's most important thinkers and his self-appointed mission to engender action at the highest level of Government, at a time when the world was teetering on the brink of bloody conflict. Every nuclear phenomenon of the twentieth and twenty-first centuries can, in some way, be traced back to this communication. President Roosevelt replied to the famed physicist on 19th October, 1939 (it seems even Professor Einstein had to wait a few months for a reply), and it read:

My dear Professor,

I want to thank you for your recent letter and the most interesting and important enclosure.

I found this data of such import that I have convened a Board constituting of the head of the Bureau of Standards and a chosen representative of the Army and Navy to thoroughly investigate the possibilities of your suggestion regarding the element of uranium.

I am glad to say that Dr. Sachs will cooperate and work with this committee and I feel this is the most practical and effective method of dealing with the subject.

Please accept my sincere thanks.

Very Sincerely yours,
Franklin D. Roosevelt. (in Stoff et al, 1991, 20)

This short but informative reply marks the beginning of The Manhattan Project, one of the most secretive transatlantic, techno-military operations that the world has ever seen. Once again, this is not the place to account for the scientific and engineering developments of the project, but what must be highlighted is the purposeful means by which the military industrial complexes of the United States and the United Kingdom sought to engineer objects to harness the innate power within uranium atoms. Four years and six months of feverish research were conducted prior to the first material utilisation of the atom, when on 16th June, 1945, the first atomic weapon was tested at Alamogordo in the New Mexico desert (Gale & Hauser, 1988). This event marks a new set of relations when one considers *the* atmosphere and humanity's conscious/subconscious usage of it, one which plays second fiddle to the material impacts of these weapons upon the cities of Hiroshima and Nagasaki, but one which - when thoughts arrive at the civilian utilisation of atomic science - triggers a reconceptualisation of the thin blue layer of gases surrounding around the earth. In other words, what becomes enrolled here was the relationship between the invisible byproduct of the atomic era, and the atmosphere which encases our planet.

5.2 The elephant in the room: the proliferation of human made ionising radiation.

> In and of itself, radiation is quite common. The Earth was born in a radioactive explosion. We live in a radioactive world. Every man and woman is slightly radioactive, since all living tissue contains traces of radioactivity. Still, despite its ubiquity, radiation is dangerous because the particles and waves emitted can alter other atoms integral and important to living organisms. (Gale and Hauser, 1988, 18-19)

The invisible agent of radiation is everywhere. As the reader reads this piece of work, they are being bombarded by radiation, silently and invisibly bouncing off and passing through their body. The universe is an intensely radioactive place - the solar winds which are emitted by every star in the cosmos are comprised of massively charged, radioactive particles, so much so that, without our protective magnetic field, the magnetosphere, produced by our planet's molten core, life as we know it could never have developed due to the damaging, if unmediated, impact of our star's energetic discharges. This interwoven phenomenon is one of the few instances when human beings can see radiation without the aid of a measuring object, and it is known as the Aurora Borealis - the deflection of the solar winds by the magnetosphere at the poles of our planet. However, there is an important difference between the type of radiation pulsating around the celestial plane and the form engendered as by-products of human-made nuclear fission. Simplistically put, this difference is predicated around the binary between natural and human-made radiation - nuclear fusion in the heart of stars and nuclear fission in human-made reactors (and bombs).

Figure 5.1 shows the contemporary periodic table, the different colours representing the half-life of each element's most stable isotope, with blue representing stability in its most natural guise, and purple being the most extreme radioactive elements, with half-lives of less than a few minutes due to their rapid rate of decay.

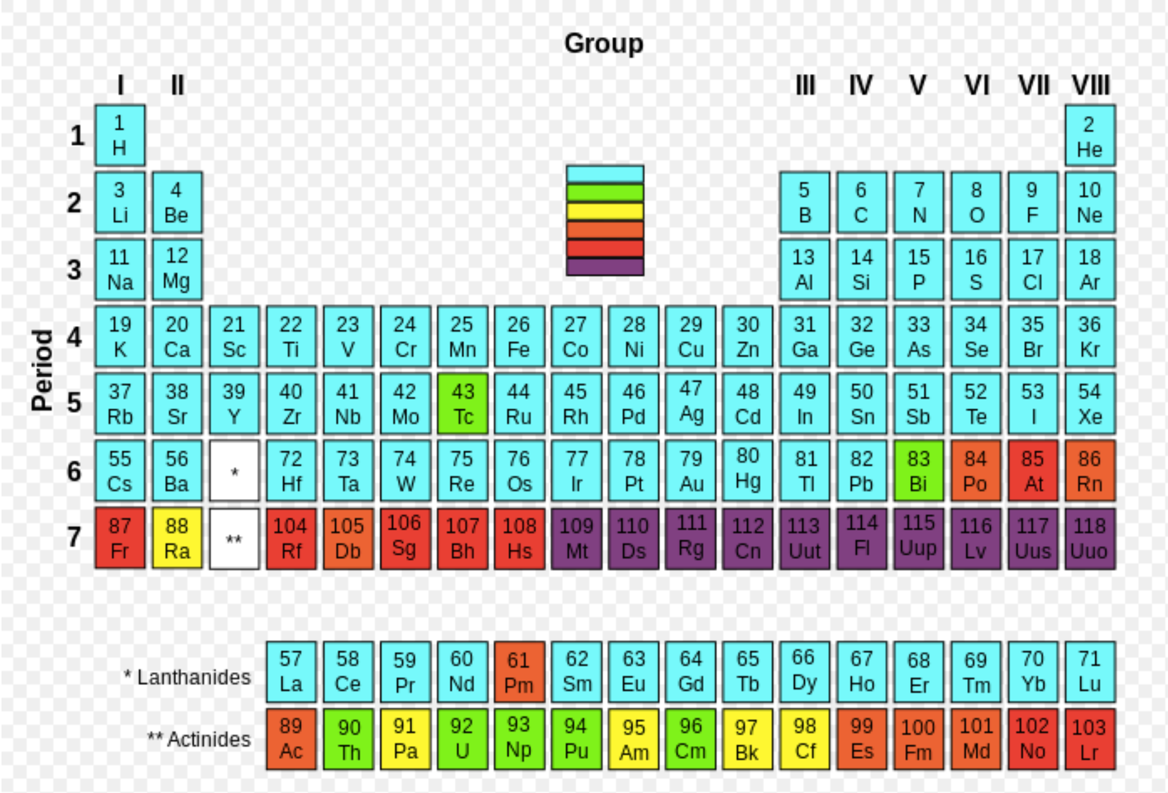

Figure 5.1: The Periodic Table (source: Scerri, 2012)

The number above the element's abbreviation identifies its respective atomic number; that is, the number of protons within the nucleus of an atom (Herrmann, 2014) - otherwise known as the proton number. For the purposes of the distinction between natural and human-made radiation, an ideal departure point is the separation of elements into natural examples and human-made iterations. Uranium is the heaviest (in terms of the number of protons in its atom's nucleus) naturally occurring element and it can be identified by its symbol 92U - every element which comes before, consequently having a lower atomic number than 92, is produced within the natural world. In other words, no human-made process resulted in its ontological existence and form.

Since the beginning of the nuclear age, scientists have been attempting to manufacture elements heavier than uranium and these new and super heavy elements are referred to as transuranic elements. As the classification suggests, they include every example with a larger atomic number than 92, that of uranium. From neptunium (93Np) to ununoctium (118Uuo) and all that lie in between, all are human-made through a process of neutron bombardment. Rhodes and Stanley (2008, 2) summarise these contemporary 'discoveries' thus: "Most of these elements are highly radioactive. This group includes the chemically toxic plutonium and americium. Up to now 26 elements which do not occur in the natural environment have been artificially synthesised".

All of the transuranic elements were, rather obviously, discovered/synthesised after the historical period accounted for above, post-1945. The scientific movement into the nuclear age brought about a new and incredibly problematic issue of terrestrial ionising radiation; that is, the form of radiation which possesses enough charge to liberate electrons from other atoms. This in turn destabilises these once secure atoms and causes them to ionise. If this happens within a biological organism the end results are mutation, cancerous growths, radiation sickness and maybe death. Prior to human-kind's experimentations with the invisible realm of the atomic, dangerous ionising radiation was a predominantly celestial issue. However, once the two atomic bombs were dropped on Japan, and the fleet of research reactors tasked with producing weapons grade nuclear material and later electricity increased in number, the amount of ionising radiation which was being produced on the planet's surface grew exponentially. Our electromagnetic guardian, the magnetosphere, protects us from cosmic ionising radiation, forming a protective arch around the earth which extends into space - akin to a huge electromagnetic umbrella. Any radiation of a similarly charged nature which is produced on the surface of our planet, will not be impeded by the magnetosphere in any way, and is therefore free to transgress across the material realm if it can attach itself to a suitable 'vehicle'.

The three most common forms of radiation emitted by radioactive material are referred to as alpha, beta and gamma (Holbert & Murray, 2015), and their charge and penetrating power varies with each form. Alpha particles are the heaviest of the three and pose little to no threat in terms of penetration as they can be halted by a few centimetres of air or a layer of skin. They are created when two neutrons and two protons are ejected from an atom's nucleus, referred to as 'alpha decay', and this discharge of neutrons is one of the fundamental ingredients required to create and sustain a fission chain reaction. This type of radioactive decay is the common mode for elements of a high atomic number, typically over 83 (Gilmore 2008). The real danger from this type of radiation is inhalation or ingestion, as once inside the human body the particle's positive charge and heavy structure results in it releasing its ionising energy quickly and concentratedly. Thus, it is useful to view an alpha particle as a hugely powerful and cumbersome person struggling to carry a very large object in their arms - as soon as this metaphorical person runs out of innate kinetic energy, they must drop their cargo where they stand and, due to its weight, the ground may be damaged by the force of this mass.

Beta radiation has much less mass and charge than alpha; in essence, this form of radiation is much smaller and nimbler. Therefore, at identical levels of kinetic energy, beta particles will travel at a much faster rate than alpha, which results in them having much more penetrating power than their alpha brethren, able readily to pass through human skin. However, as beta particles are essentially high energy electrons, they are negatively charged. This physical trait, when taken in conjunction with their considerably lower mass, results in them being repelled by other positively charged atoms, reducing their impact upon biological material. It may help to visualise beta particles/radiation akin to a Scottish Highland midge, reviled by most, constantly repelled and not as biologically impacting as their warmer climate sibling the mosquito. They can cause harm in particular situations, but much of the time the damage caused is superficial due to their lack of toxins and physical might. One facet of this account which must be highlighted before pressing forward is the variable of charge. If a beta particle has an identical charge to an alpha, it will be just as harmful, if not more so due to its penetrating abilities (Okun 1987).

Gamma emission/rays, unlike their alpha and beta cousins, are nondeviable by a magnetic field, due to their neutral charge (as apposed to the positive alpha and negative beta forms), and they are of an extremely penetrating character (L'Annunzita & Micheal 2012). Whereas alpha radiation can be halted by skin and beta by a few inches of metal, gamma rays can penetrate several inches of lead. They are hence the strongest iteration of the three and are a form of electromagnetic radiation of an extremely high frequency, which is therefore massively ionising (Siegbahn 1965). The fundamental difference between gamma rays and the other two examples comes down to their materiality. Alpha and beta radiation are both particle based, in that they have an incredibly small physical ontology, but gamma rays are pure energy and do not rely on a material object to travel (Rhodes & Stanley 2008), hence the 'ray' naming. They are engendered within the decay, either alpha or beta, of certain subatomic particles. In these instances, the new nucleus is created in a high energy state, and subsequent movement into a lower energy state results in the emission of a gamma-ray photon. This loss of surplus excitation energy grants gamma rays existence. Thus, when certain elements experience radioactive decay, they can emit a combination of alpha (or beta) and gamma (Khabaz 2012). As previously mentioned, gamma radiation is a form of electromagnetic radiation, akin to the likes of radiowaves, microwaves and light visible to humans.

All of these forms of radiation are charted within the electromagnetic spectrum, presented in figure 5.2. As one moves from the right to the left of the table, the energy contained within each entry increases, and gamma rays represent the most energy-laden on the spectrum. The process, accounted for above, through which they attain this power is referred to as nuclear transitions (Gilmore 2008); that is, the release of excess energy post radioactive decay.

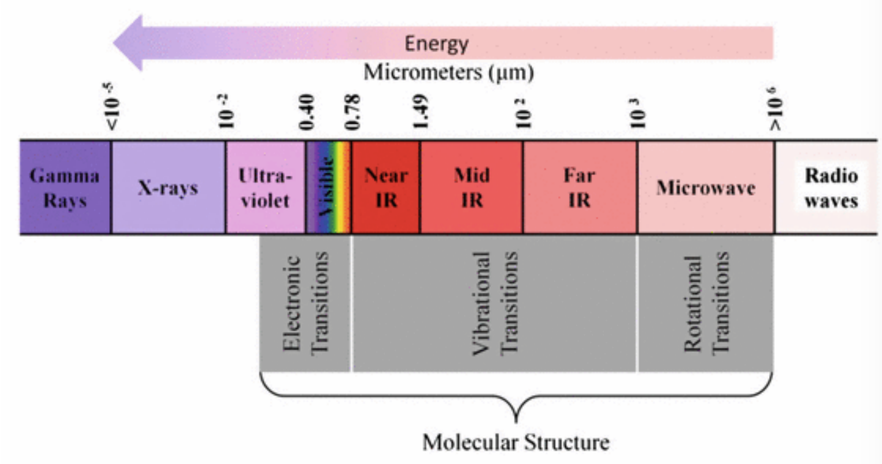

Figure 5.2: Electromagnetic spectrum (source: Stedwell & Polfer 2013)

Although gamma rays are immaterial in nature, they are produced by atomic evolutions within matter itself. Thus, the appearance of gamma rays represents a means to render visible the presence of radioactive particles within a landscape, due to their symbiotic connection to radioactive decay. Furthermore, terrestrially orientated, naturally occurring gamma radiation is a rarity, with the dominant emitter being thunderstorms (Smith *et al* 2011). As the main producer of gamma rays in our celestial neighbourhood is the spherical fusion furnace at the centre, the appearance of such rays on terra firma can be linked to the presence of radioactive substances, typically those created from the fission process. This interconnected relationship between radioactive matter and gamma rays forms the foundation of techniques used to map the spread of radioactive caesium from RBMK no4, and it is referred to as gamma-ray spectrometry. This scientific method of identification and analysis will be comprehensively covered in the following section, which accounts for the European Commission's (1998) *Atlas,* as it has become the staple means to render visible the blanket of invisible radioactive particles across the landscapes of Europe.

At this juncture, a moment of reflection is required to consolidate and focus all that has been covered thus far. Prior to this chapter, the research has been squarely focused upon the object of RBMK no4, the event of the disaster, and the material actions spawned by the object's agency. The quasi-scientific account of the development of atomic sciences and the invisible agent of radiation is tasked with identifying the means to render visible this tiny, and horrifyingly dangerous realm of the material world. At this point, these abilities have only been hinted at, but what has begun is the process of describing what radiation entails, in its most fundamental form. It is now known that there is a divide within the periodic table between natural and human-made/synthesised elements, and this divide is crucial when allocating an 'origin' to radiation; ionising radiation is dangerous as it is laden with energy which can destabilise atoms within biological entities; the existence of terrestrial ionising radiation is interwoven with the incorporation of nuclear technologies; there are three prominent forms of radiation, with varying abilities and dangers; and the relationship between the material/particle nature of alpha/beta and the appearance of gamma rays is a fundamental tool to account for the presence of invisible radioactive material.

Prior to exploring the huge body of work conducted upon the spread of radioactive material from Chernobyl, a brief journey into the toxicology of these substances also required, primarily to instil analytical balance, one which takes seriously the impacts that these unstable elements can have upon biological organisms. The following section hence completes the account of radiation, that is, rendering visible the material impacts upon biological organisms of the 'invisible'.

5.3 The fleshy material dangers of ionising radiation.

> The accident caused the largest uncontrolled radioactive release into the environment ever recorded for any civilian operation; large quantities of radioactive substances were released into the air for about 10 days. The radioactive cloud dispersed over the entire northern hemisphere.... Two radionuclides, the short-lived iodine-131 (131I with a half-life of 8 days) and the long-lived caesium-137 (137C with a half-life of 30 years), were particularly significant for the radiation dose they delivered to members of the public. (UNSCEAR 2008, 47)

The above quotation is taken from a UN report on the radiological impacts of the Chernobyl disaster. Iodine-131 and caesium-137 were the radioactive elements of greatest concern and danger in the post-event epoch, with the former requiring a rapid response due to its short-lived decay, and the latter representing the most pressing material issue due to the longevity of its half-life. Furthermore, the spread of the isotope caesium-134 was also a concern; however, due to its shorter half-life, roughly half that of caesium-137, it only played a 'supporting role'. This factor is represented within the European Commission's (1998) *Atlas,* the multilateral project which represents the empirical core of this chapter. Although every chart, table and map is focused upon delineating the spread of the longer-lived isotope caesium-137, the deposition patterns of the two were identical and caesium-134 is therefore subsumed into the geovisualisations. As the spread of this radioactive element represents the core of the *Atlas*, the following section will account for its impacts upon biological organisms. It should be noted at this stage that the following account is predicated around doses of radiation akin to those delineated within the *Atlas*, meaning a dose which a member of the public could have received as a consequence of the Chernobyl disaster, meaning low to medium doses. In the case of the firemen, whose actions were covered in the previous chapter, the doses received were so out-of-the-ordinary that the trajectories of damage enacted upon their bodies were so extreme, and so uncommon, that the process of meticulously accounting for them would, in effect, represent a morbid excursion, one which would only be applicable to a handful of people in the history of the atomic age.

As early as the 1960s radiobiologists had begun scientifically to test the impact of ionising radiation upon animals, typically rats. In a series of experiments which administered several radioactive elements to rat test subjects, Burykina found that, when the rats:

> received 134c in a dose of 40 cu/g subcutaneously, quickly occurring death was observed on the 9th day (rat No.19) and on the 11th day (rat No.16). In addition to the symptoms of an acute radiation syndrome and of all above-mentioned changes (weakness, lack of reactivity, reduction of appetite), dysentery, sanguinolent discharge from the nose, and actor dispelea were also observed. Several of the other subjects received a 20cu/g dose, half of that given to the above mentioned group, and these rats lasted for 42 days post administration. In one case, the rat died after 251 days. The conclusions gained from this experiment were that 134c causes death of rats in a case complicated by pneumonia on the 99th day, in a case free of complications on the 328th day of observation. (1962, 85)

Thus, from this early experiment we begin to recognise a few characteristics of radiation and its effects upon biological organisms, notably that it engenders a host of embodied adverse effects, a series which slowly degrades the quality of life within the affected organisms, and subsequently causes death in all of the test subjects. What it does not indicate, however, is how it produces these harmful effects; that is, what its material trajectories of damage are, and how these impacts can be rendered visible. As an aside, the geographies of the ethics of animal testing have received a wealth of attention, predominantly within the sub-discipline of more-than-human geographies (Miele *et* al 2005; Veissier *et al* 2008; Roe 2010 etc).

Blood is the great workhorse of all mammals, the oil that drives their 'engines' so to speak - if the quality of blood decreases, then it cannot power/feed the body's vital organs, which leads to their failure. What is of key relevance to the task of rendering visible the devastating impacts of the invisible realm of radiation is the identification of the types of cells which compose blood. Simplistically put, the two cells of significance here are red (granulocytes) and white (lymphocytes), with the former outnumbering the latter roughly five hundred to one in humans

(Bain 2006). Over the course of the liquid's 'working life', its compositional cells will deteriorate; when this occurs, the now useless cells are subsequently disposed of by the spleen - if the body is working as it should - and the replacement cells are produced by cell division of stem cells. This happens in two different bodily areas, dependent on which cells are being replaced (Kitchen 2007). Red blood cells are predominately manufactured within bone marrow, and white are engendered within lymphoid gland tissue, which is spread across the body. The biological impacts of ionising radiation features a latency, in that, unless an unfathomable amount of radiation is absorbed in one short sitting, the detrimental health effects it can cause will not be immediately apparent. Thus, one of the most efficient means of identifying its presence within the body is through its adverse relationship with blood.

Alexander states that:

> it is almost impossible to irradiate any part of the body without exposing some lymphatic tissue. Lymphocyte counts are therefore a very sensitive biological indicator for detecting radiation… The fall in circulating lymphocytes in the blood is so early and so marked because these cells are extremely sensitive to interphase death. Radiation causes their rapid lysis and this means that a large mass of lymphoid tissue disintegrates (1965, 139-140)

Red blood cells do not have such an immediate reaction to the presence of ionising radiation as they are not as susceptible to interphase death, but, as there are a far greater number of red cells, in comparison to white, they collectively deteriorate at a naturally faster rate. This process is hastened by the appearance of ionising radiation (Kitchen 2007). Akin to the white cells, the bodily system for replenishing the red cells is damaged by the circulation of radiation. As mentioned above, bone marrow is the primary producer of red blood cells and, after exposure to radiation, only a limited number of new cells can be produced, and the vital biological work that blood has to enact which the bodily system cannot be completed due to its now inferior cellular structure. In other words, radiation can be identified within the body by contrasting the universal statistical average of red and white cells within the blood, taken from a healthy organism, with a sample from a patient suspected of being exposed to ionising radiation. If there is a marked decrease in white cells and, after 24 hours, also a decrease in red cells, one can conclude that invisible atoms of a radioactive substance are being circulated around the patient's system. Blood and its intricate circulatory and replenishing systems enter into a vicious cycle with ionising radiation: the liquid provides the invisible invader with a vehicle to travel around the body, causing huge amounts of damage in the process. Akin to a parasite, ionising, particle-based radiation embeds itself within the body's 'great workhorse', rapidly eroding its biological usefulness and, crucially, destroying the organism's ability to reproduce the cells which have been destroyed.

The cited works of Alexander were conducted fifty years ago, and medical science's understanding of this process has increased greatly over this period. Pratt (2013, 4) states that this nexus between ionising radiation and blood creates chemical intermediates which damage the DNA, in essence destabilising its compositionally stable atomic structure, and that these events include "mitoitc cell death especially in bone marrow and mucosal tissue, and the activation of inflammatory responses that can lead to blood vessel damage". Thus, these two accounts from two very different eras of scientific research allude to the same phenomenon, albeit in a different language.

Furthermore, if we return to the experimentation upon the rat test subjects in the 1960's, Burykina (1962, 97) observed the same results, in that the levels of white blood cells within the rats plummeted after the administration of caesium-134. Exploration of the radiobiological impacts of radiation tracks its primary path of damage, identifying what aspects of the interconnected system are impacting first and foremost. It has also provided one means of casting aside its cloak of invisibility, engendered a means of accounting for its ontological affects. Granted, it is through a scientific process of educated deduction, but this logical practice is one of the cornerstones of the radiological sciences. In theoretical terms, this account also creates a connection to the entity of *the* atmosphere and its role within the Chernobyl disaster. Without the aid of the thin blue layer of gases, and the weather patterns of the time, the caesium which poured upwardly from RBMK no4 could not have travelled far - the atmosphere was its material vehicle, one which carried the object's materiality and agency across the landscapes of Europe. Blood and its circulatory system performs a similar role on the scale of the body. Thus, within this example, the physical transgressions of caesium and its ionising ontological impacts were facilitated by two primary vehicles: one at the planetary scale, *the* atmosphere, and at the other end of the scale the individual body, blood and its 'hydraulic' pump, the heart. They were both tragic 'natural' regions of RBMK no4's network.

At this juncture, bolstered by these biological insights, the second half of the descriptive account of radiation will return to the Chernobyl disaster, and the practices of the doctors and nurses of Hospital no 6 in Moscow, in a bid to connect these quasi-abstract medical concepts with the material realm. What should have become apparent from the above cited experiments (with rats and caesium-134 exposure) is the lack of a chronologically linear scale with regards to the impacts that ionising radiation has upon biological organisms. Furthermore, its biological impacts are not universal, in that they do not adhere to a linear trajectory of damage (counter to the claims of the Linear No-Threshold model of radiological protection which is covered in chapter 7). For reasons that the medical sciences are yet to understand, every animal, plant, insect and human reacts to its destabilising impacts differently, in that one person might exhibit catastrophic health problems from a relatively small dose, while another could live a full and unaffected life despite a far greater exposure. This is graphically evident within the memoirs of Dr Peter Gale (1988), the American bone marrow transplant specialist who traversed the Iron Curtain, at the height of the Cold War, to treat the victims of the Chernobyl disaster.

The damage caused by ionising radiation to bone marrow is one of its key trajectories of damage; thus, transplanting bone marrow into an irradiated patient is one of the primary means of tackling the spread/harm cause. In the 1980s, bone marrow transplants were state of the art medical procedures, due primarily to the nexus between the logistical complications of finding a suitable donor, with an identical physiological make up to the patient, and the appearance of 'graft-versus-host disease' (Tai *et al* 2008). The former is predicated upon genetic viability, and Gale (Gale & Hauser, 1988, 43) states that, "The ideal bone marrow donor is an identical twin, the automatically perfect genetic match. Other siblings offer a twenty-five percent chance of compatibility, the probability of a genetic match between two unrelated people is about one in ten thousand". Thus, the logistics for the identification of suitable genetic matches for a patient are sizeable, and in the 1980s the global donor register had only 150,000 donors on it. Graft-versus-host disease is the condition that occurs when the immune system of the host attacks the donor bone marrow as it views it as an invading presence (due to the mismatch of genetics), and begins to enact its genetically programmed biologically defensive mission. Le Blanc *et al* (2004, 1411) state that a severely acute case of graft-versus-host disease, post "allogeneic stem-cell transplantation is associated with high mortality.". In other words, if a patient suffers from this condition after a bone marrow transplant, even today, there is little chance of saving them. Thus, when Gale embarked upon this mission to help the irradiated victims of the Chernobyl disaster, he faced not only the biologically devastating effects of ionising radiation, but also the logistics of finding donors and the misguided defence of the patient's immune systems.

5.4 "I'm going to the Soviet Union on behalf of the International Bone Marrow Transplant Registry."

The following subsection recounts this human actor's time spent treating a selection of victims, a cross-section of patients, which highlights the non chronologically/damagingly linear characteristics of ionising radiation. Furthermore, Gale's memoirs reassemble a part of Chernobyl's network where he played a central role. His relocation to Moscow represents the first 'action' in a series engendered by the object of the reactor; and, upon the commencing of his work, he put in motion a heterogenous node of action tasked with tackling the materiality of the nuclear non-human. This node was a little-known section of RBMK no4's network, and, for this purposes of this chapter, it renders visible the biological impacts of the invisible realm of the atomic through a case specific example. It should be noted at this stage that the only detailed record of Gale's visit is that of his published memoirs, and any quotation cited is taken from them.

Gale's journey across the Iron Curtain is unique, and could be described as the personal mission of a medical doctor, provoked by the agency of a broken nuclear non-human. At the time, he was a world-leading expert in bone marrow transplants, a technique used to combat leukaemia. Gale learned of the disaster on 29th April, and deduced that his expertise would play a pivotal role in keeping patients alive, due to the potential exposures to ionising radiation. Through a network of influential actors he had met throughout the years, notably an international business man named Dr Armand Hammer, he extended the offer of medical help to the Soviet Union, a bold — and considering the geopolitical context of the period — very brave action.

Gale arrived in the Soviet Union on 2nd May, 1986, six days after the explosion in RBMK no4, and was informed that thirty of the most seriously injured patients had been transferred from Ukraine to Hospital no 6 in Moscow. The successful implementation of bone marrow transplants is further complicated by the variable dose of radiation received: "less than a certain radiation dose, a bone marrow transplant is unnecessary. And over a certain dose, it's useless because the patient will die anyway for reasons other than bone marrow failure." (Gale & Hauser,1988, 52). Thus, the need for an accurate and efficient system to quantify a patient's inner levels of radioactive particles was essential. Gale found that the Soviet medical industry had a pre-established system in place, one which accounted for three haematological variables, and made an educated judgment based on these three variables. One he claimed to be very impressive, another example of the use of blood work to render visible the invisible realm of unstable atoms. The process of bone marrow transplants features two stages (three if you count the identification of a donor); the first is the extracting of bone marrow from the donor, and the second is the administration of it into the patient's system. These are the two main tasks that Gale conducted until 12th May, 1986, the date of the last transplant - after this date, his time was spent enacting the complex aftercare work.

Although there were over 200 members of Chernobyl staff present at the time of the explosion, the majority of the people he treated were the surviving firemen, whose heroics have been covered in chapter 4. He states that, due to the aforementioned latency of radiation's effects, and the internalised nature of its attack upon the body, there existed a form of denial with regards to the severity of their predicament. Granted, every firefighter had suffered terrible burns at the hands of unstable atoms, typically beta radiation, but, anyone who has been physically burned before knows that, unless they cover the vast majority of the body, burns are not life threatening. However, out of the five fire fighters he first examined, none were chosen for bone marrow transplants as the incredibly high dose to which they had been exposed had resulted in their organs being damaged beyond repair. For eight days the hospital suffered no deaths, post bone marrow transplants, but, on the 10th May, Vladimir Pravik, one of the firefighters whose actions were described in the previous chapter, died. Pravik's death was not unexpected as he was only awarded a transplant because a viable donor was immediately available, one who offered a genetic match well above average. His death highlighted that, even with such a match, his body was simply not equipped to combat the unstable atoms that he had endured.

Gale returned to the United States at the end of May, then a week later flew back to Moscow. Upon his return he learned of several more deaths, but three firefighters, Versinian, Tarmosian and Palmarchuk, were showing signs of improvement after their transplants. The fascinating, albeit tragic, aspect of this is that several of the patients who had died received a notably smaller dose of radiation than the patients who remained. At this point, the official disaster death toll had reached twenty-six. For Gale, "many of the victims had been [his] patients, and [he] felt a special sense of responsibility and loss" (Gale and Hauser, 1988, 127). This statistic further highlights the ambiguous nature of radiation's impact upon biological organisms. Gale was a world leading expert in the primary means of combatting exposure to radioactive substances, and yet even he could not save the majority of his patients.

Over one month passed before the next event of significance to this account, and it features the death of Versinian on 17 July. As mentioned above, Gale had believed that this patient was on the mend, and that the transplant had been a success, but seemingly overnight his blood count had fallen rapidly and he succumbed to his injuries. Versinian's death was a prime example of the aforementioned latency of radioactive impacts. Over two months had passed since his exposure and in that time he had received marrow from a genetically suitable donor, but, due to the longevity of caesium-134/137, it had remained in his system and begun to erode the new cellular material administered to him by Gale. This decrease in the quality of his blood had resulted in mass organ failure, due to the blood's inability to supply the organs with the nutrients required to function. Tarmosian and Palmarchuk survived their ordeal and were two of the few whose transplants effectively saved them. There is no record of their dose rate, but, as they were firemen, it is safe to assume that they were subjected to some of the highest levels out of any of the emergency workers who arrived in the immediacy of the explosion. Thus, two of the few survivors of the actions of Gale in Hospital no 6 were among the group which had received the highest dose, a fitting example to highlight the non linear nature of impact that ionising radiation has upon biological organisms.

For some, the health effects of Chernobyl's radiation were so catastrophically impacting that nothing could save them. As mentioned earlier, all that has been described thus far has been within the remit of a quasi-normative dose of radioactive material; that is, a dose under 100mSv, one which is, say, 50 times that of a background dose. Granted the above mentioned firefighters would not fall into that category, as the levels of radiation to which they were exposed were thousands of times the magnitude of natural background rations, but, Dr Gale and his team made the educated decision that these men were in the 'Goldilock' dose range for a bone marrow transplant, and thus treated them accordingly. However, to conclude this section, we must account for the victims who had exposed themselves to suicidal doses, as a means of firstly rendering visible their heroism in the face of the invisible aggressor of unstable atoms, and secondly to highlight the worst case scenario. This will be achieved by means of the contexualisation provided by the actor present and responsible for the lives of these patients. As Gale explained:

> Of all the patients I saw in the Soviet Union, it was Dr Orlov who affected me the most. A young man about my age, he'd gone to the reactor building after the explosion to help stabilise the condition of injured firemen prior to their removal. As a doctor, he understood the nature of radiation. Yet he stayed in the reactor area for three hours, sacrificing himself to save others. Finally, feeling what he termed 'a metal taste in his mouth and headache sickness', he retreated to the triage area. But even there, he continued his efforts
>
> When I first saw Orlov, he already bore signs of severe radiation sickness. Black herpes simplex blisters scarred his face and his gums raw.... Then, over several days, the skin peeled away and his gums turned fire-engine red like raw beef. Ulcers spread across his entire body. The membrane lining his intestines eroded and he suffered bloody diarrhoea. We administered morphine to ease the pain, but even when delirious, he remained in agony. The nature of radiation burns is that they get worse rather than better, because old cells die and young ones are unable to reproduce as a result of the

damage. Towards the end, Orlov was barely recognisable and his death, several weeks after the disaster, was merciful." (Gale and Hauser 1988, 58)

Figure 5.3: Mitinskoe Cemetery, Moscow - the resting place of the 'officially recognised victims of the accident (source: Butyrin 2013)

The purpose of this chapter thus far has been to characterise the entity of radiation, and to engender a quasi-scientific means through which the social sciences can grasp its ontological intricacies, subsequently providing a means to comprehend its dangers. This account has been conducted primarily to contextualise the previous chapter's accounts of the event of the Chernobyl disaster, to render visible the very damaging impacts that radiation can have upon biological organisms. Furthermore, albeit much less noble yet no less important, has been the identification of a means through which the invisible realm of unstable atoms can be rendered visible, reflecting the conceptual alignment with this research's ANT theoretical and methodological sensibilities. We have seen that alpha and beta radiation is particle-based and thus achieves an ontologically material existence, and that one of the fundamental means through which to identify its presence within biological organisms is through its nexus with the cellular composition of blood. Hence, on the scale of the body, radiation's cloak of invisibility has been cast aside, and its material presence rendered visible.

With this empirical and conceptual logic covered, and the biological significance of radioactive elements, such as caesium, documented, thoughts will now turn to the European Commission's

(1998) *Atlas*. This shift in perspective encompasses an impressive multilateral project, *as-well-as* another invisible agent, one which played a crucially important role within Chernobyl's network - *the* atmosphere.

5.5 Radioactive atmosphere - the meteorological transportation of unstable atoms from RBMK no4

> Terrorism, from an environmental perspective, voids the distinction between violence against people and violence against things: it comprises a form of violence against the very human-ambient 'things' without which people cannot remain people. In other words: air and atmosphere - the primary media for life, in both the physical and metaphorical sense - only became an object of explicit consideration and monitoring in domains such as aero-technics, medicine, law, politics, aesthetics and cultural theory in response to their terrorist deprivation. (Sloterdijk, 2009 25)

The above extract from Peter Sloterdijk's compelling historically-guided philosophical journey through the twentieth century focuses upon the aggressive appropriation of *the* atmosphere, a process he names 'atmo-terrorism'. The context, with regards to this quotation, is the development and utilisation of gas warfare during the Great War - the production of poisonous gases, and their subsequent highjacking, as means of transport, of the 'local' atmosphere surrounding the trenches in France. The core argument of Sloterdijk's work is structured around three distinctive hallmarks of the century, actions and practices supposedly distinguishing it from all that has come before. These are: the practice of terrorism, the concept of product design, and environmental thinking. The heterogenous range of contemporary engendered objects, their material impacts, and the actions spawned by their purposefully detrimental utilisation has resulted in a truly new era of techno-socio existence, one which has the scope and power fundamentally to alter the thin blue layer of gases which encase our little blue spaceship. Thus, the products, actions and effects of these three characteristics are interwoven and interdependent, in that the significance of each is heightened when set alongside its two brethren. Each one is credible in its own right, but when taken as a whole, they mutually support each other, resulting in a distinctive and potentially very dangerous network of things, actors and actions.

The concept of terrorism is of key interest to this chapter, and the possible ambiguity surrounding the intentionality of actions of this nature. Sloterdijk (2009, 28) states that terrorism, "can only be understood when grasped as a form of destructibility. It exploits the fact that ordinary inhabitants have a user relationship to their environment, that they instinctively and exclusively consume it as a silent condition of their existence." He goes on to classify a terrorist as an actor who gains an explicative advantage over an enemy/target's life world and exploits it to cause harm. From this elongated definition of the act and the actor responsible for it, one can deduce that said exploitation is predicated upon an intention to harm or disruption of the conditions of life of the target. This could be in the form of a gas attack, atmospheric engineering or, on a smaller scale, the utilisation of the 'atmosphere' of a specific localised space to rid it of a pest. The last example is accounted for by Sloterdijk as he explores the peace time (between the two world wars) development of the pest control industry, a sector of capitalism which owes a technological debt to the military industrial complex. The parallels between this sector and the civilian nuclear industry are plain to see.

Throughout his philosophical journey, Sloterdijk accounts for a host of examples which vindicate his interconnected hallmarks of the period, and the insistence on terrorism being an intentional act never wavers. Due to the phenomena he provides as evidence, this classification is readily justified, particularly when he accounts for the nuclear era. Radioterrorism began with the United States' bombing of Japan, humanity's first and only use of atomic weapons in anger. This term captures the ushering in of the era of invisible aggression of both unstable atoms and the rays of pure energy produced by their decay. This development forms a new branch, or subsection, of his meta-conceptual structure of atmo-terrorism, a more specific means of identifying the ontology of the atmospheric appropriator.

When theorising radioterrorism, Sloterdijk only provides the example of the Enola Gay's atomically destructive mission and chooses not to branch into other, more ambiguous aspects of the nuclear age. It could be argued that this decision was made to protect the conceptual foundations of his arguments; the 'difficulties' that these other nuclear-orientated phenomena could pose to it may challenge such a steadfast conceptualisation. However this seems like a missed opportunity. Granted the dropping of Little Boy and Fat Man was one of the most pivotal moments in the history of the twentieth century, formulative for the era of atmoterrorism, but the simple fact remains that these two weapons were of the weakest and most feeble ever produced by nuclear-equipped states. In reality, the amount of radioactive material released into the atmosphere, and by proxy the 'level' of radioterrorism, was low, so much so that both cities have been completely rebuilt and today house millions of people. Obviously, one cannot ignore the material impacts that these bombs had upon the human population, but this section of this chapter is focused upon *the* atmosphere and its appropriation/irradiation.

Therefore, in the history of radioterrorism, its meta-impacts upon *the* atmosphere and the global public, two main phenomena, are of much greater significance. These impacts are indexed by the extensive testing of three stage thermonuclear weapons by, but not exclusive to, the United States and the Soviet Union during the Cold War; and also the nuclear non-human at the heart of this research project, RBMK no4 of the Chernobyl NPP. The meltdown at the Japanese nuclear power plant at Fukushima in 2011 should arguably join these two as another significant instance of radioterrorism; but, due to its ‘liquid’ orientated transportation of radioactive material, a fitting label for it would be ‘terrorism from the water’, rather than the air. The Cold War weapons tests was a practice of testing state-of-the-art technology *as-well-as* a pompous exhibition of destructive might - an unfathomably carnivorous black hole for monetary/human resources and a futile race towards a passive-aggressive stalemate of mutually assured destruction. The latter, RBMK no4, arguably represents the worst human-made accident the world has ever seen, the universally feared yet scarcely believed catastrophe of both machine and atmosphere. The former was a series of actions by the respective countries' military industrial complexes, and the latter was an event produced within the civilian sphere of society. Regardless of the orientation of these events, both released huge amounts of radioactive material into the atmosphere which, unavoidably, impacted upon the life worlds of the civilians of a range of different countries. So, the question remains, were these actions an act of terrorism? The testing of thermonuclear weapons could be readily classed as such, although, the ‘terror’ was intended to be evoked by the might of the weapons, with the pollution of the atmosphere as an unavoidable side effect. Beck *et al* state that:

> From 1945-1980, over 500 weapons tests were conducted in the atmosphere at a number of locations around the world. These tests resulted in the release of substantial quantities of radioactive debris to the environment... the impact of weapons fallout will continue to be felt for years to come since a contaminant baseline has been imposed on the ambient radiation environment that will be an important factor in the assessment of past and future releases of radioactive materials into the biosphere. (2002, 591)

The two aspects of note within this statement are the number of atmospheric weapons tests and, crucially, the imposition of a contamination baseline on the ambient radiation environment. This imposed baseline is an epistemological construct, one which raises the accepted ambient level of radioactive emission within the environment of the United States. Thus, in this instance, the user interface between the environment and the residents of the areas within the immediate atmospheric sphere of influence of the weapon test sites has been damaged, and the implementation of a new level of accepted ambient radioactivity is a means of obscuring this fact. In other words, erecting mirrors and clouding their gaze with smoke in a bid legally and politically to cover up the existence of ‘unnatural’ radioactive material.

The Nevada Test Site was the primary location within continental North America where hundreds of controlled explosions were conducted, the majority of which were underground, but a notable percentage were atmospheric detonations. Each resident of the surrounding area was issued with a booklet produced by the United States Atomic Energy Commission in 1955, titled *Atomic Test Effects in the Nevada Test Site Region*. In an open letter to the recipients, the test manager, James E Reeves, stated:

February, 1955

A MESSAGE TO PEOPLE WHO LIVE NEAR NEVADA TEST SITE:

You are in a very real sense active participants in the Nation's atomic test program. You have been close observers of tests which have contributed greatly to building the defenses of our country and of the free world. Nevada tests have helped us come a long way in a few, short years and have been a vital factor in maintaining the peace of the world. They also provide important data for use in planning civil defence measures to protect our people in event of enemy attack.

Same [typo within original document] of you have been inconvenienced by our tests operations. At times some of you have been exposed to potential risk from flash, blast. or fall-out. You have accepted the inconvenience or risk without fuss, without alarm, and without panic. Your cooperation has helped achieve an unusual record of safety.

In a world in which free people have no atomic monopoly, we must keep our atomic strength at peak level. Time is a key factor in this task and Nevada tests help us 'buy' precious time.

That is why we must hold new tests in Nevada.

I want you to know that in the forthcoming series, as has been true in the past, each shot is justified by national and international security need and that none will be fired unless there is adequate assurance of public safety.

We are grateful for your continued cooperation and your understanding.

James E Reeves
Test Manager

Due to the twentieth century being the era which spawned the nuclear age, and by extension radioterroism, it appears that Sloterdijk could/should have added a fourth hallmark to his list; that of targeted and sustained political subterfuge regarding the risk, dangers and environmental presence of ionising radiation; that is, the use of an ever evolving propaganda machine tasked with comforting citizens in the face of state-led atomic practices. Not only does this letter metaphorically connect the surrounding population to the nation's test programme, it can, with the aid of hindsight, seem rather blatantly to obscure their very real material participation *within* them. Akin to any locale which has experienced some form of radioterrorism, the rates of thyroid cancer increase within the surrounding population, and Nevada is no different (Gilber *at al* 1998).

It is safe to assume that the United States Government did not intend to harm its civilian population during these tests, or to cause destructive damage to the life worlds encased within its borders. However, the fact remains that both of these material eventualities were a by-product of the practices of the atmospheric testing of atomic weapons at Nevada (and of course the Marshall Islands in the Pacific Ocean). As presented within the above letter, the official line was that these tests were of paramount import to national security, and this claim, if it was to be believed, rendered visible the intentionality of the acts. However, claiming this import within an open letter to the general public who were exposed to state-created ionising radiation does not obviate the fact that the United States Government committed an act of radioterrorism upon its own people. Therefore, when contextualised against the backdrop of the Cold War arms race, the intentionality surrounding the act of 'terrorism' is blurred, particularly with regards to the actions of the United States.

In contrast, the Soviet Union also conducted hundreds of atmospheric tests within their own borders, including the detonation of the AN602 hydrogen bomb on the island of Novaya Zemlya in northern Siberia. Nicknamed 'Tsar Bomba', this nuclear non-human was the largest and most powerful weapon humanity has ever produced (Hutchinson, 2003), notably larger than anything produced by the United States. This relentless drive for megatonnage power was a hallmark of the Russian model of atomic weapon development, where the classic mantra of 'bigger is always better' perfectly describes their technological trajectory, whereas the United States chose to focus on a more challenging aspect of the technology, namely accurate delivery of smaller, more compact bombs. Mother Russia has never been kind to her residents; the winters are brutal, the terrain inhospitable, and her vast resources are locked away in mountain ranges hundreds of miles from population/industrial centres. Nonetheless, the expansive nature of her geography, and the uninhabitable conditions of her northern regions, presented the Soviet Government with ideal test facilities for weapons of this nature. The site of the Tsar Bomba test is 1,417 miles from Moscow, and a distance of 880 miles away from Arkhangelsk, the closest settlement of significance (population of 348,000). The distance between John o' Groats and Land's End is 874 miles, so it is safe to conclude that the distances between the major population centres and the test site of the Tsar Bomba were significant. When these distances are placed in contrast beside the spatially connected relationship between the Nevada Test Site and the city of Las Vegas; that is, the minimal milage between the United State's main testing facility and a major population (and tourist) centre, the awarding of the label of 'radioterrorism' is further legitimised.

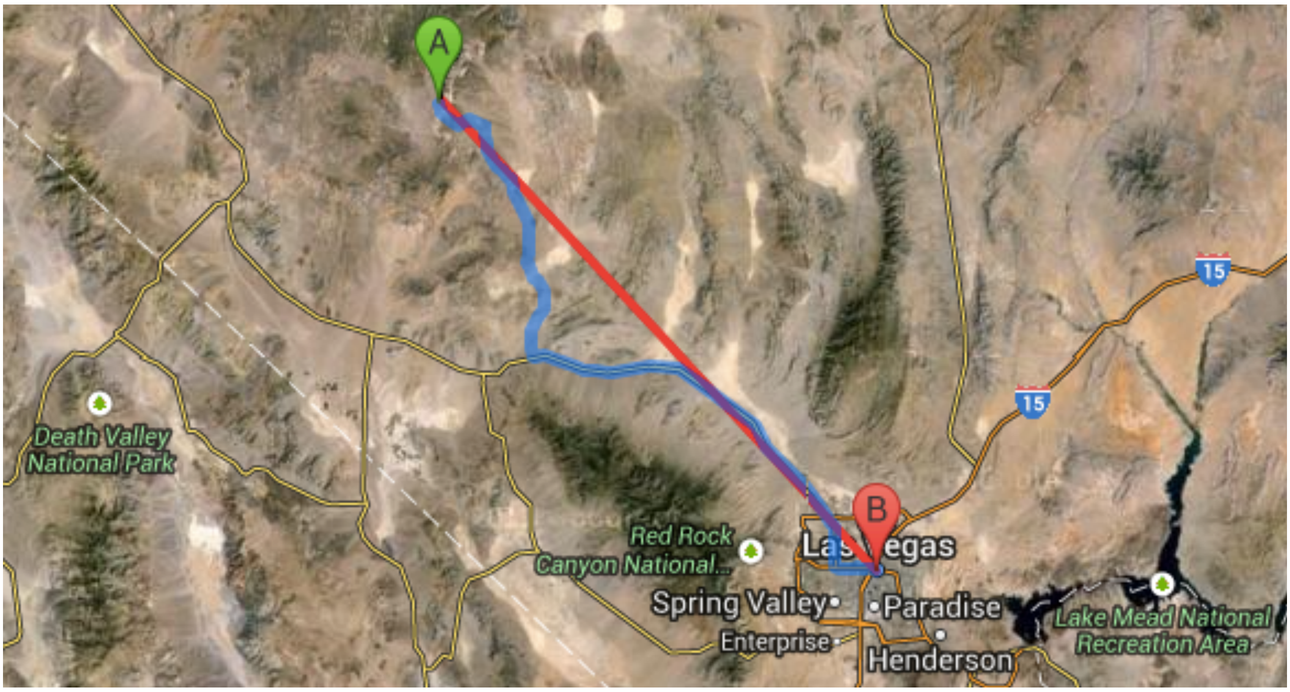

Figure 5.4: GoogleMaps image of Las Vegas and the Nevada Test Site (source: GoogleMap)

Figure 5.4 is a satellite image delineating the landscape and the two sites of significance, with a separating distance of just eighty eight miles. Furthermore, three national parks are within close proximity, as is the city's primary drinking water reservoir. Today, fifty years on from the main testing within the Nevada site, the radioactive elements will have decayed into oblivion; but, akin to the numerous victims of Chernobyl, genetic mutations caused by ionising radiation from these weapons test could have been biologically embedded within the surrounding populations, notably the residents of Las Vegas. Interestingly, minimal research has been conducted upon this nexus between human genetic mutations and the dosage from the weapons testing. Several studies have focused upon such a phenomenon within the area's wildlife (Theodorakis *et al* 2001), and a huge amount of work has been conducted upon the migration of radionuclides within the region's groundwater (Bentley *et al* 1983, Rush et *al* 1983, Cole *et al* 1996, Smith *et al* 2003 etc). Yet, for reasons one cannot confidently assert, a lacuna exists with regards to the radiation's impacts upon human actors. Beck (1991), when speaking about his risk society, states that regulatory systems are designed to dilute and mitigate responsibility with regards to risks. This lack of sustained scientific enquiry into the genetic impact of the weapons testing upon the population of Las Vegas provides tentative evidence of this type of hierarchical protection system of the risk society; that is, if no research has been conducted upon this invisible issue, then the state cannot be held accountable for the biological damage caused.

Thus, it could be argued that the biological legacy of these atmospheric tests, unavoidable due to their placement so close to a large population centre, will live on within the generations that followed the civilians residents within this area at the time. In other words, the explication of the user interface between these residents and the atmosphere that they breathed to subsist on the most basic level had been eroded by these acts of radioterrorism: a biologically destructive act by means of vastly complex objects specifically designed to exploit the forces within atoms, supplemented by the casting of an obscuring veil of political subterfuge, one which epistemologically alters the ontological impacts on the environment. It is the perfect encapsulation of Sloterdijk's three hallmarks, *as-well-as* the proposed addition of a fourth.

All of the above is not intended to exempt the Soviet Union from this discussion, or from being classed as radioterrorists, but is merely a means of problematising Sloterdijk's conceptual structure and furthering what he began by means of materially orientated, historical examples. As this research is centred upon the Chernobyl disaster the above account is tasked with engendering a form of impartiality, one which takes seriously the United States' acts of radioterrorism upon its own citizens, and thereby avoids (or even reverses) the normal geopolitical representations of the disaster by 'the West'. Without this discussion about the atmospheric testing of nuclear bombs, the conceptual construct, arguably, would be asymmetrical as the release of radioactive material from these tests is of a comparable nature to that of Chernobyl. Now, this account is not seeking to cast the United States as *intentional* radioterrorists, and a more fitting title might be pragmatic radioterrorists; in that they *had* (in their opinion at the time) to test these weapons, and the Nevada facility represented the best option. On the other hand, the Soviet Union seemingly took every precaution to situate their testing grounds as far from major population centres as possible, and therefore within the weapons testing context, their classification as 'radioterrorists' is a stretch. However, within the context of the Chernobyl accident, an event outside of their control and desires, but with huge radiological consequences, the Soviet Union did in fact *become* radioterrorists, but not by choice. Thus, *intentionality* is of key importance, in that a country could inadvertently become a 'terrorist' of radioactivity without *actively* intending to do so - an unintentional radioterrorist.

In order to 'achieve' this unwelcome status, the Soviet Union was not alone, they had a willing accomplice, one that cannot be controlled, bargained with or accurately predicted. This invisible transporter played a pivotal role within RBMK no4's impact upon the countries of Europe, yet it is rarely spoken about. We are now talking directly about *the* atmosphere, and its weather patterns of the weeks following April 26th 1986.

5.6 Rendering visible the atmosphere and the reassembling of the geography of the Chernobyl accident

5.6.1 Stage one: stationary appropriation.

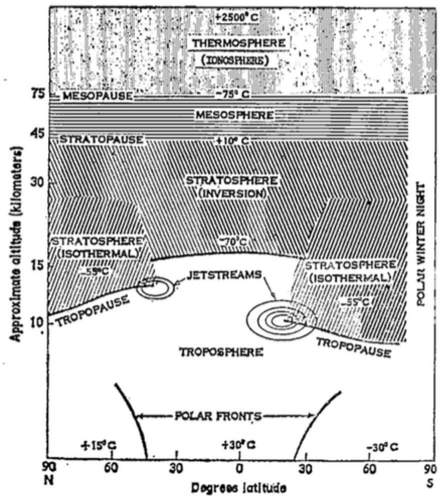

Figure 5.5: Visual delineation of the atmospheric layers of construction (Source: UNSCEAR, 1962, 238)

Figure 5.5 is taken from the report of the UN's Scientific Committee on the effects of atomic radiation. Produced in 1962, it was an international effort to understand the emerging dangers which ionising radiation, produced by atmospheric weapons tests, posed to the general populace. It is a visual representation of the earth's atmosphere and the various layers which comprise it. Barry and Chorley (2009, 13) state that air "is a mechanical mixture of gases, not a chemical compound," and note that its varying compositions have different densities. This results in their vertical 'stacking', which in turn forms the different 'spheres' of the atmosphere. The presence of water substances is of great importance to the continuous 'movements' within its structure, and also to the study of radioactive fallout, especially with regards to the Chernobyl disaster. Saha (2008) states that water substances exist in three phases, vapour, liquid and solid, and climatic changes in heat prompt the change in structure of water. This results in a vertical movement between the different spheres: the lower the density of the water substance, the higher it resides. When water is in liquid form, it transgresses into the low levels of the atmosphere where it can bond with "quantities of dust, smoke and toxic gases." (Saha, 2008, 10). If these two situations align, the risks associated with these hazardous material entities being transported downwardly to terra firma by a mixture of gravity and liquid water are greatly increased.

It should be noted at this stage that the attention being paid to the bonding of radioactive fallout with liquid water in the troposphere is firstly down to the uniqueness of the Chernobyl disaster, and secondly, due to its subsequent difference from nuclear weapons tests. 'Wet deposition' of RBMK no4's toxic innards - that is, the scattering of this material across the landscapes of Europe by means of rainwater - has been the primary concern of the scientific community. Kinser (2001,4) adds that, "Case studies of wet deposition are difficult and rare… [and] nuclear weapons tests are performed on clear days, avoiding dangerous radioactive hot spots associated with precipitation". Therefore, the ability to render visible the material processes which resulted in the absorption of radioactive elements within this moist 'wet' layer of the atmosphere are crucial.

A simple assumption would be that, when in liquid form, the subatomic particles (alpha and beta particles) are simply trapped within this form and subsequently bonded. A description of this kind is simply not enough to satisfy analytically the scientific community; rather, for instances both celestial and terrestrial, Kirchhoff's Law is used to account for this material absorption. This law is predicated upon the fact that certain media absorb radiation of a particular wavelength, but, at the same time, emit radiation of the same wavelength. This binary is dependent on the residual energy contained within the ionising radioactive element (Liou, 2002). Furthermore, the rate of emission of radiation is contingent on both temperature and wavelength; this rate is intrinsically connected to how the absorbing element reacts under conditions of thermodynamic equilibrium within the atmosphere (Oliveira 2013). This equilibrium is not universal within the atmosphere, and only appears at certain heights and gaseous compositions; thus, "in a localised volume below about 60–70 km, to a good approximation, it may be considered to be isotropic with a uniform temperature" (Oliveira 2013 14) and said balance/radiation absorption is achieved. Looking back at figure 5.5, the 'local' area of the atmosphere being referenced here includes the stratosphere, tropopause, and troposphere.

For the purpose of this account of how the atmosphere appropriated and transported RBMK no4's radioactive legacy across the landscapes of Europe, these three layers are all significant, the troposphere being the most so. It is crucial to note at this stage that different media are 'transparent' to specific types of radiation and this material characteristic allows them to be selective of the frequencies with which they interact, such that they will thus not absorb or emit if their ontological structure is not attuned to a certain wavelength. However, rather unfortunately, water vapour "is almost transparent to short-wave solar radiation but absorbs heavily in long-wave radiation" (Saha, 2008, 82), the latter being the frequency variant of gamma-rays and certain types of beta decay, both of which were released from RBMK no4 in abundance. In other words, Kirchhoff's Law facilitates the explanation and subsequent calculation of the amount of radiation absorbed within sections of the atmosphere. It is dependent on a uniform temperature, which in turn allows for the identification of specific heights/spheres within the atmosphere where this binding can take place. Finally, certain elements interact with particular formations of radiation, and, for the disposition of radioactive fallout, liquid water's penchant for long wave radiation, the type most common within the fission process, results in the vertical transportation to the ground level of 'terror from the air'.

5.6.2 Stage two: horizontal transportation

At this juncture, the material process of how radiation is bonded with elements within the atmosphere is known; however, thus far, this description is somewhat of a 'stationary' account. As the 'horizontal' transportation of radioactive debris from RBMK no4 is of primary concern, that is, the atmospheric processes/movements which connected the site of the Nuclear Power Plant in the Ukraine to the distance landscapes of Europe, thoughts must now turn towards turbulent and ever-changing dynamics of the different spheres of the layer of gas which encase the earth. Such a quasi-scientific account uncovers the physical processes which produced the most impactful aspects of the nuclear non-human's geography. Akin to the act of showing the articulations of the fractional stages of a calculus equation, prior to the provision of the final numerical output, this process reassembles the geography of RBMK no4's radioactive spread from the reactor from a meteorological perspective.

As previously mentioned, the troposphere was of key importance, primarily due to the format of the first stage vertical transportation in the ten days which followed the accident. This release was in the form of a 'traditional' fire, in the sense of an element combusting at ground level, one which conducted itself in a similar fashion to others of this nature. The smoke from such a blaze reaches a ceiling, with regards to the height it can travel into the atmosphere, a major departure from the disposition of fallout from atmospheric weapons tests. One may believe that the more powerful a bomb, the greater the absorption of radiation within the atmosphere, and to an extent this is the case. However, once a weapon reaches a certain megatonnage/yield, its verticality results in the breaching of the uppermost limit of the atmosphere and a notable percentage of its energy and radioactive fallout is simply cast off into space. The UNSCEAR report (1962) states that 'partitioning' of radioactive debris between the local, troposphere and stratosphere occurs during atmospheric weapons tests, and this process is governed by three factors: "[the] weapon yield, height of burst, and the meteorological conditions" (1962, 238). Thus, as most atmospheric weapons were tested at a position of verticality - that is, the majority of their radioactive material was transported 'upwards' - therefore, this debris comfortably reached the stratosphere. The report predominately focuses on the stratosphere, the primary and long term place of residence for radioactive debris from weapons tests, but there is a notable section detailing the movement between it and the troposphere - the section of the atmosphere where such debris can be appropriated by liquid water or reaching a height where gravitational forces may pull it to ground level.

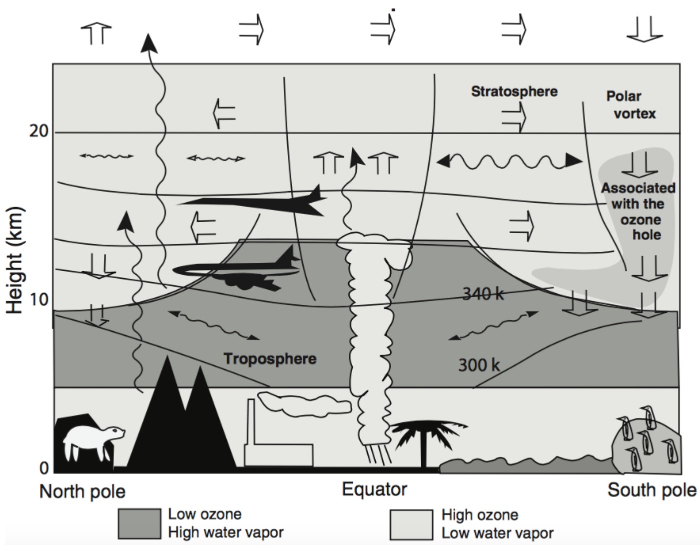

Figure 5.6: graphic representation of global movement of atmosphere (source: Mohanakumar, 2008)

Due to the combustable nature of the Chernobyl release, transgression into and, by proxy residence, in the stratosphere was not achieved. Figure 5.6 depicts the transportation and movement processes in the atmosphere from the tropics to the poles, and the process of combustion release is represented by the factory and its smoke chimney on the x axis. One can identify that the uppermost limit of its reach is the top of the troposphere and its mass is filtered into this first sphere and moved either in a northerly or southerly direction, depending on which hemisphere the phenomenon inhabits. Chernobyl's coordinates are 51°23'22.1N 30°05'58.7E, and so the left side of the diagram is of relevance here, and its innate atmospheric directions and systems highlight that air is moved towards the poles. The tropospheric, that is, the climate of the tropics at the equator, is the driving force of the atmosphere, the area of the globe which pumps warm air through the troposphere and into the stratosphere. If the Chernobyl NPP was geographically situated closer to the Equator, its vertical reach would have been magnified significantly, and the catastrophic potential for its radioactive fallout to reach the jetstream, 'the motorway of the sky', could have been realised.

This northwardly moving circulation system is the 'meta' physical force which governed the patterns displayed by the surface deposition of radioactive fallout from Chernobyl. As one travels down through the atmosphere towards surface level, the direction of the wind is not as completely regulated, albeit it is still governed by the higher tropospheric system, and the importance of high and low pressure, and warm and cool air masses, increases. The meteorological situation of the ten days following the accident epitomised this 'dynamic' nature of the lower atmosphere, that of the lowest reaches of the troposphere. Knap's (1988) analysis of the four days following the accident highlighted that a prevailing cold continental pressure system was situated to the north east of the Nuclear Power Plant, and also that, crucially, a North Atlantic low pressure system was situated off the west coast of Britain. The appearance and consequent interaction of these two systems produced a series of precipitating troughs across west and central Europe, during all phases of the release from RBMK no4. These two contrasting pressure systems were responsible for the far reaching spread of fallout, and the divergent microcosmic wind patterns at local levels were the result of the macro interaction between the two systems. The filtration of the meta air circulation system dragged these two pressure systems into close proximity, and the creation of rain water within the clouds facilitated its bonding with the fallout.

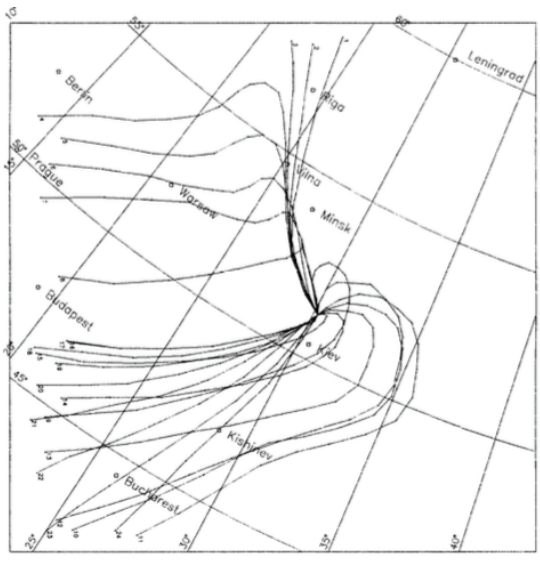

Figure 5.7: Prevailing wind trajectories in the days after the Chernobyl accident (source: European Commission, 1998, appendix A)

Prior to providing an account of the practices which produced the European Commission's (1998) *Atlas,* and here facilitated the rendering visible of ionising radiation, one final aspect of the meteorological system of the immediate days after the accident has to be represented: that of the aforementioned dynamic wind conditions which carried the radioactive plume in several directions (figure 5.7). These changes in the wind's direction were the most influential 'action' of the atmosphere, the driver which steered the physical transportation device. The most comprehensive account of these winds is, unsurprisingly, given in the *Atlas*. Figure 5.7 is taken from the *Atlas* and it shows the sum total of the trajectories of the plume at various points, up until 1st May 1986, with inputs 1-4 taking place on 24th April, 5-8 on the 26th, and 21-24 on 1st May. The document does not account for the 9-20, but, one can deduce that these wind trajectories will have taken place during the four day period between 26th April and 1st May. The two dominant patterns are of a northerly and south westerly orientation, towards Scandinavia and central Europe respectively. Graziani and Zarimpas (1988) further analyse these conditions, stating that up until the end of the major radioactive release from RBMK no4 on 8th May, a predominantly northerly wind resulted in the transportation and disposition of material over regions and countries to the south of the Nuclear Power Plant. This ever changing pattern of wind direction produced distinct spatialities, an evolving landscape of exposure and fallout hot spots across the entirety of Europe. It was these divergent actions of the atmosphere which resulted in the most geographical aspects of the disaster - mappable material transgressions produced by geophysical phenomena. Furthermore, when network thinking is applied to this spread, the spatial visualisation of the nuclear non-human's physical reach comes into focus. Prior to this meteorological account, the agency of the object had been shown to be inwardly orientated, in that, after the explosion, it rapidly drew human actors towards its physical form. This influx of people was tasked with primarily stopping the emission of radioactive elements from the core of RBMK no4. Thus, when taken together, these two parts of the meta account begin to render visible the collective whole of the nuclear non-human's new agency: the frantic attempts to calm its newly tenacious innards and the widespread radiological material impacts of its transgressions.

This section has detailed the ontological atmospheric modes of transport that carried the radionuclides from the bowels of RBMK no4 and deposited them across the landscapes of western Europe. Thus, a fitting way to conclude this section, prior to moving onto a detailed evaluation of the *Atlas* is with an account of the research conducted upon the material and biological impacts of these unstable atoms. This short empirical journey is tasked with attaching the scientific processes of section 5.6 with a real world example, one intrinsically connected to

RBMK no4. As section 5.4 dealt with the human/radiation nexus, this exploration will detail aspects of the 'natural' world; that is, the biological impacts of radionuclides, transported by means of the atmosphere, upon the wildlife of the Exclusion Zone.

In 2006, the IAEA published *The Chernobyl Forum Report,* a significant document that evaluated, among other things, developments within the Exclusion Zone in the two decades after the accident. One of the report's concluding arguments stated that, within the Exclusion Zone, the effects of radiation from RBMK no4 were negligible, relative to the impacts of human inhabitation. Mousseau and Møller (2011) took exception to this stance, claiming that the report was based on very limited empirical data. They go on to argue that the Exclusion Zone represents an ideal site for analysis, as high and low dose areas can be found in close spatial proximity, hence within a singular ecosystem. They state that;

> There is really no other place on the planet that provides such potential to address fundamentally important questions at a spatial scale that is of relevance for scientists and policymakers wishing to understand the effects related to a nuclear disaster. (2011, 39)

Granted, in order to transgress this 30km space, the radionuclides did not require much 'transportation' from the atmosphere, but its closed borders and static (from human activities) woodland areas allow for an evaluation of how these invisible, 'unnatural' and unstable invaders impacted the natural environment. In other words, the Exclusion Zone could be seen as a petri dish: a site with sections of unchecked radioactive contamination, an ever present migration of animals and a vibrant biosphere, a metaphorical melting pot of noteworthy biological processes caused by the agency of ionising radiation. Thus, akin to how the data from the survivors of Nagasaki and Hiroshima has been used as a scientific 'benchmark' to study the impacts of ionising radiation on humans (this shall be covered in chapter 6), the empirical data from the Zone has been used to gain an understanding of how the radioactive dispersion could impact the other forms of organic life.

The Chernobyl Forum Report (2006, 137) states that "the populations of many plants and animals have expanded, and the present environmental conditions have had a positive impact on the biota in the Chernobyl Exclusion Zone". This statement, when taken at face value, does seem valid, due to the reclamation of the space by natural processes. In Chapter 1, the ethnographic account of the researcher's most recent trip to the Zone represented Pripyat as a forrest, rather than a city, due to the surprising growth of the space's trees/plants. However, this chapter is interested in the scientific; the difficult, complex and dangerous invisible realm of ionising radiation, the molecular (McCormack 2007) so to speak. Simplistic accounts of the increase in biota does not render visible the molecular/genetic impacts of the radioactive dispersal. Thus, to satisfy the analytical appetite of this chapter, deeper we must travel.

A sizeable body of work has been conducted upon the vegetation within the Exclusion Zone. Kovalchuk *et al* (2004, 357) plainly state that "constant exposure to mutagens, such as UV and ionising radiation, chemicals, heat, drought, and cold, forces plants to either adapt or die"; and within the Zone, multiple examples highlight the evolutionary prowess of biotic life. Kovalchuk *et al*'s research assessed the rates of mutations within Arabidopsis plants, and found that, as time passed, plants that grew within high dose concentration areas had developed resistance mechanisms to deal with their new unstable neighbour. These plants thrived in areas with dose rates several times the magnitude that killed identical examples within the team's control group. Their conclusion highlights the ability of this type of plant to regulate their genome in the face of the energy from the ionising radiation - in other words, their genetic structure fortified itself over the generations to combat against mutations. Thus, in this instance, the biotic is shown to be resilient in the presence of high-dose rates, a conclusion shared by several other studies (Abramov *et* al 1992, Kovalchuk *et al* 2003, Yoschenko *et al* 2011).

The genetic resilience of plant-life is not directly transferable to red-blooded creatures. Mammals are the most radiosensitive group compared with other terrestrial animals (Geras' kin *et al* 2008). This is due to the processes covered in section 5.3, notably the blood circuitry acting as a bodily vehicle for the transportation of radiation. Hinton *et al* (2007) calculated that the number of rodents inhabiting the area around the nuclear non-human fell drastically in the years following the accident; and, even with the innate high breeding patterns of the species, this fall in numbers would result in the unlikely probability of long term manifestations of mutations.

Mobility, it seems, is a crucial prerequisite of a species being able to combat an influx of ionising radiation. In essence, if a creature can remove itself from the site with ease, then the likelihood of survival increases. This is the case with the birds of the Exclusion Zone, but, even with increased mobility, several species still exhibit radiation damage. Camplani *et al's* (1999) analysis of the Zone's barn swallow population found lower levels of leukocytes and munoglobulins within subjects that reside within the space. These findings are in line with the account of section 5.3, and the impacts of radiation on the human body.

The concept of ‘mutations’ evokes certain, sensationalist, images, whereas the scientific meaning of the term refers to genetic deviations from an entity’s norm - microscopic changes that could lead to cancers and other conditions. The research conducted upon the red-blooded creatures of the Exclusion Zone highlights the similarities between the effects of radiation upon them and upon humans. Generally speaking, a decrease in white blood cells is an ever-present byproduct of ionising radiation. The purpose of detailing these non-human impacts of ionising radiation is a means of connecting the atmospheric transportation of RBMK no4’s radioactive innards to another domain of reality or another ‘world’. It creates an alternative window on the ontological impacts of the radioactive cloud prior to exploring empirically the internationally constructed tome tasked with mapping its physical deposition.

5.7 Radioactive agency and scientific actions: the final ability to render visible the invisible

Figure 5.8: European deposition patterns of C-137 (source: European Commission, 1998, plate 1)

Figure 5.8 delineates the sum total of the monitoring works conducted by European scientists after the disaster - the actions tasked with identifying, categorising and mapping the spread of caesium137. As the red areas represent the most irradiated sites, one can partially reassemble the wind patterns discussed in the previous section. The northwesterly arcing winds of 26th April resulted in deposition over Scandinavia and the United Kingdom, and the predominantly southwesterly winds during the remainder of the release period account for the higher and more concentrated levels of fallout over eastern and central Europe. Sanderson *et al* (1997) state that twenty-five percent of the total amount of material released occurred during the first day after the accident, a much larger mass than on any of the subsequent days.

This factor explains the semi high deposits of caesium-137 to the north of the NPP, particularly in Finland, Sweden and Norway. When figures 5.7 and 5.8 are taken in conjunction, they provide an excellent insight into the actions of *the* atmosphere and the emergent material situation that its winds engendered: a melee of wind and radioactivity, one which, when visualised in the form of a map, renders visible the physical trajectories of the wind and its radioactive passenger. These maps allow for a geographic/geophysical reading of the event, one which reassembles the activities and accounts for their coating of the landscape. In other words, they form a cartographic discourse.

As previously mentioned, caesium137 was chosen as the element of identification due to the longevity of its half-life, its beta and gamma decay modes, and the simple fact that it is a product of nuclear fission, one which does not occur naturally. Furthermore, aerodynamics and size came into play, in that, for a particle to be suspended and carried on the wind for days on end, it must be sufficiently tiny, and of modest weight, otherwise the gravitational pull of the earth would have torn it from its lofty mode of transportation. Kinser states that:

> The Chernobyl fire generated massive quantities of submicron particles carrying Cs-137. Small particles, 1um in aerodynamic diameter and smaller, have a fall speed of less than about 1.0mm/s… [these] particles from the Chernobyl accident containing Cs-137 are mainly confined to the small category because of how they were formed in the fire and smoke. (2001, 5-6)

In the case of countries situated over 500 miles away from the site of the explosion, and who subsequently experienced fallout from RBMK no4, the only type of element ontologically equipped to reach them was Caesium-137. This was most definitely the case for the United Kingdom. The section below represents a tracing of an influential human actor who contributed heavily to the *Atlas*, and who, more importantly, was prompted to create a new practice of radiation monitoring. In other words, this actor's actions represent another emergent series prompted by the agency of the nuclear non-human - actions which resulted in the now widespread deployment of his system. Professor David Sanderson is the actor, and his practice is known as Airborne Gamma Ray Spectrometry (AGRS).

It should be noted that several measuring techniques were deployed to create the data within the *Atlas,* and all seemingly depended on the expertise of the scientists of each participating country. For example, the primary mode of detection in Norway was ground-based, featuring the collection of precipitation at designated sites (Backe *et al* 1986), whereas scientists in Germany chose to sample susceptibly absorbent biological organisms under the trajectories of the radioactive plume (Spettel & Palme 1987). This disparity within the research techniques resulted in a mishmash of sampling maps, and a heterogenous blend of data sets; this culminated in an overall deposition map of Europe being difficult to calibrate, due to the varying statistical inputs and the non-universal means through which caesium was accounted for, a factor not officially recognised within the *Atlas*.

The purpose of focusing on AGRS is firstly its deployment within the United Kingdom (one of the countries furthest away from the site), secondly its relationship with the agency of the nuclear non-human, and finally the logistical accessibility of the actor responsible for its creation and utilisation. Furthermore, the practice of Gamma Ray Spectrometry (GRS) in general represents the final piece of the puzzle, the crucial method which facilitates the scientific rendering visible of invisible ionising radiation within the Chernobyl context. Tyler states that the GRS is fundamentally based on the principle that the detection of gamma photon energy points to the presence of radionuclides within a landscape, and that “the detection of gamma rays is critically dependent upon the gamma ray photon undergoing an interaction that transfers all or part of the photon energy to an electron in the absorbing material.” (1994, 41). Thus, the object of a gamma ray spectrometer - that is, the ontological device needed to perform the practice - must include this type of material in order to account for the presence of this form of radiation.

Tyler goes on to state that spectrometers of this nature have two detectors, one inorganic scintillator, and one solid state semiconductor - and the larger the size of these two detectors, the greater the accuracy of the spectrometer. These objects are, by design, reactive in nature, in that they are constructed with two materials within them that actively absorb the photon energy within the gamma rays. In other words, the material byproducts, or the physical ‘translations’, of this interaction are the first means of accounting for the presence of these dangerous rays. Due to the rarity of naturally produced gamma rays, this mutation within the detectors discloses the presence of radiation - in the case of Chernobyl caesium-137 could therefore be readily identified within any given landscape due to its beta and gamma decay modes; a deductive and very clever system, metaphorically akin to the work of a detective, tracing backwards to their target using the evidence available.

The above account of these objects, and the practices associated with their usage, has so far been devoid of any notions of mobility, or the issues therein. If, hypothetically, one possesses situated knowledge which points to the presence of an invisible radioactive source within a distinct spatial location, a gamma ray spectrometer can be placed within the space and it will diligently amass any evidence available to it. However, without prior knowledge/evidence of this nature, spatially informed actions cannot be conducted, in that, they have no 'directing' script from which to read. This was most definitely the case in the post Chernobyl epoch. The total area associated with the deposition of fallout from RBMK no4 was simply not known, and the specific locations of the wet deposition were of even greater uncertainty. Therefore, the need for a rapid means of rendering visible these radioactive hotspots was required, one which could produce results more quickly than practices being conducted on the ground level. In other words, the script had to be written in an extremely short period of time. Attaching the object of a gamma ray spectrometer to a vehicle, or simply walking around with one in the hand, are the only two feasible means of conducting this type of research on the ground, both of which are time consuming and place the actor in charge of the object in close physical proximity to the radioactive element emitting the gamma rays. Furthermore, as previously stated, the necessity for large mass detectors is required for the spectrometer to reach 'high sensitivity' levels, resulting in a heavy and cumbersome object which is not conducive to easy mobility. Set within the context of nuclear accidents, where time is very much of the essence (as the necessity of stopping radioactive elements entering the food chain is paramount) a means through which large areas can be mapped in a short period of time was needed.

The issue of mobility, the limited timescale and, of course, the presence of caesium-137 from Chernobyl prompted Sanderson to 'pilot' a new technique for the deployment of gamma ray spectrometers. AGRS has now emerged as a premier means of accounting for the presence of radioactivity over large areas in the response to nuclear emergencies (Scott *et al* 2000). In essence, a suitably large spectrometer, typically containing sixteen litres, or more, of inorganic scintillator, and at least one semiconductor detector (Cresswell *et al* 2005), is attached to a plane which can comfortably fly at around 100m in altitude. This aircraft is then flown in straight lines over an area where it is *believed* that radioactive nuclides are present, and the readings gained can *'prove'* their presence. Sanderson *et al* (2004) state that this approach to environmental radioactive mapping has several key advantages, namely that:

> High sensitivity y-ray detectors, typically large volume NaI(T1) scintillators optionally combined with Ge semiconductors, installed in the aircraft are capable of taking environmental radioactivity measurements every few seconds, thus providing a sample rate some 10 2- 10 3 times greater than other approaches. The radiation detector averages signals over fields of view of several hundred dimensions, resulting in area sampling rates some 10 6 - 10 7 times greater than ground base methods (2004, 214)

Furthermore, the recording of the height/ground clearance of the flights and the data from the gamma ray spectra are used to quantify the sources of the emission, consequently narrowing down the accurate geographical location of them (Sanderson *et al* 1994). In other, less scientific words, this mixture of RBMK no4's agency, and geophysical/physics logistical techniques produced an adaptation of an existing system of measurement: one which produced a 'discourse' that could be mapped, and, by proxy, prompted the agency to direct a series of actions which would impact upon these spatial locations, *as-well-as* the lives of the people connected the sites. Prior to the Chernobyl disaster, the world had never encountered a situation where this type of practice was essential on such a large scale.

The translations of the data accumulated by these AGRS flights produced distinct spatialities, and contributed towards the meta cartographic process of mapping the disposition of caesium-137 on the European scale, as highlighted in the plate at the outset of this section. Figure 5.9 is of the region of the United Kingdom which experienced the highest levels of caesium-137 disposition, and thus the most dangerous radioactive hotspots. The area delineated is the west coast of England, between Carlisle in the north and Preston in the southernmost tip of the map.

The two most affected areas are highlighted with orange markings. Due to its distance from the site of the NPP in Ukraine, the United Kingdom only received a tiny amount of the total mass of radioactive release, some 0.83% (European Commission, 1998, 24), the highest concentration of which was situated in the northern region of this map. The larger highlighted area to the south is unique in its origin, in that the radioactivity was *not* transported to the United Kingdom by means of the atmosphere from the nuclear non-human at the centre of this research project. Sellafield is one of the world's premier nuclear waste reprocessing facilities, and within the plant are the Windscale Piles, a reactor once tasked with creating weapons grade nuclear fuel. In 1957 a fire broke out in the facility and released radioactive substances into the surrounding area. It was ranked category 5 in severity on the International Nuclear Event Scale (Chernobyl was a category 7).

Figure 5.9 Map of caesium-137 deposition over the north west of England. (European Commission, 1998, plate 34)

The Sellafield incident was the United Kingdom's first act of 'unintentional radioterrorism' on its home soil: the accidental, yet environmentally damaging, release of ionising radiation into the atmosphere surrounding the facility. At the time, akin to the above mentioned tactics utilised by the United States during their Nevada bomb tests, the severity of the accident/release was politically mitigated. Therefore, a publicly available map of the disposition was never released. Sanderson claims that when he started his AGRS of the United Kingdom, looking for caesium-137 from Chernobyl, his actions were greeted by pressure from the United Kingdom government as they were not keen for a map of this nature to be produced and universally disseminated. He also stated that, during some of his first flights, he had discovered radio caesium in a condition which highlighted that it had been decaying for several years, which, rather obviously, ruled out its material connection to the newly destroyed NPP in the Ukraine.

One can readily see why the British Government were not keen to see this actor (Sanderson) conducting his measuring practices, outwith their control, as one of the two major radioactive hotspots in the United Kingdom was bound up in older government energy policies (and military interests). This is an important facet of the *Atlas*, one which only becomes visible when the scale of the regional level is analysed. Relative to the meta-map of Europe (figure 5.8), the size of the

UK hotspot in question is dwarfed by the huge areas of dark orange, produced by RBMK no4. However, the significance of this site to the United Kingdom is paramount, in both its origin and the actors responsible for its creation. It is unclear whether or not the authors of the *Atlas* were aware of the political complications surrounding the site, and only during the description of the Chernobyl disaster is the Windscale accident referenced (for means of a contrast to highlight the severity of Chernobyl). Therefore, whether intentional or accidental, the inclusion of data pinpointing this nuclear accident in the United Kingdom has resulted in a mediation, one which subsumes the ontological impacts of it into the meta 'Chernobyl discourse'. Without the information attained from Professor Sanderson, one would not be able to affix the correct source of this radioactive hotspot within the English landscape, even though it is geographically represented within the *Atlas*. Thus, in this instance, the ethos of 'following the actors' has resulted in the ability to render visible information that would have been out of reach of the analysis; here, oddly, Chernobyl has still travelled, but not through its own radioactive fallout – rather through what measuring that fallout has inadvertently also measured.

This example of the process of scientific data translation into a cartographic language, and subsequent mediation through subsuming of it into a wider, more focused discourse, has interesting connections to the philosophical works of Sloterdjik. The collective whole, that is, all of the works conducted across the entirety of Europe and Russia, reassemble the material spread of the former Soviet Union's most damaging act of radioterrorism. The outcome is an internationally constructed tome of translations of statistical measurements into cartographic images which reassembles, arguably, the most fundamental geography of the accident. The ontological reach of RBMK no4, facilitated by its atmospheric vehicle of transport, was so inescapably massive that no political control could be imposed upon it, particularly (but not exclusively) from the Soviet perspective.

Granted, in the immediacy of the days which followed the explosion, the Soviet government did attempt to layer the quasi-standardised veil of political subterfuge over their atmoterrorist actions, and to keep invisible the carpet of unstable atoms that they inadvertently spread across the landscape of Europe. However, the abilities of the medical and geophysical experts to render visible these tiny invaders cast these evasive actions into the realm of futility. It could be argued that this continental movement, and its series of scientific actions, in effect produced the evidence which forced the Soviet Union fully to embrace its policy of Glasnost; that is, a new focus on 'openness'. The aforementioned British example is not as black and white, but it does further illustrate the additional characteristic of atomic political subterfuge. The material evidence of its actions is statistically and visually represented within the *Atlas,* yet the *meaning* behind its presence is omitted. As mentioned above, at the time of the Windscale accident, the Government of the United Kingdom obscured its very real environmental impact, or, to put it another way, their pollution of the atmosphere/environment by means of atomic processes. Although the *Atlas* explicitly accounts for the existence of this radioactive hotspot, it does not delineate its true source, and simply subsumed it into 'the deposition of radio caesium from the Chernobyl disaster': for the government of the United Kingdom, a serendipitous mediation of meaning, and one which places a further epistemological layer of subterfuge on their iteration of the 1950's.

The *Atlas* is an impressive body of work, and facilitates the ready identification of the geographical spread of RBMK no4's radioactive fallout. It is the end product of a large number of actors' actions, all engendered by the agency of the nuclear non-human. It extrapolates, condenses and subsumes various research methods, techniques and their subsequent findings into a meta-discourse and creates a version of reality guided by the (assumed) objectivity of science. It is the product of a network, the final discourse of a constellation of actors all acting with the shared goal of rendering visible the invisible. It is a totalising account of the material spread of radioactive fallout, a viewpoint into a realm that human beings are not biologically equipped to explore in person. The multiplicity of the sites measured and scrutinised contributes towards this dominant view, the all-seeing depiction of the catastrophic wrong-doings of a once mortal enemy of 'the free world'. It zooms in on specific locales, telling the story of how this distant nuclear non-human cast its toxic legacy on their flatlands, and immediately zooms back out to the continental scale, colouring its topographical landscape in bright orange warnings of unstable atoms. This description appears somewhat facetious, but that is not the intention.

The very real material actions taken as a result of the findings which make up the *Atlas* stopped unstable atoms entering the food chains of most of the countries who took part. For example, in Norway, meat raised in affected areas underwent stringent radiological measurements procedures (Brynildsen *et al* 1996); a similar tactic was deployed in England and Wales (Nisbet and Woodman 2000); and, in Italy, bans were placed on milk with elevated caesium levels (Venuti *el al* 1991). Regardless, the viewpoint portrayed is not one devoid of subjectivity, nor, as has been highlighted above, splashes of political subterfuge. Furthermore, France's participation is almost completely non-existent, and any account of the disposition within its landscape highlights minimal exposure. One may suggest that it was simply too far away from the site of the NPP to experience any fallout, and at first glance, devoid of any sustained critical thought, one may be fooled by such a suggestion. Akin to the experiences of Sanderson with the British Government, it would not be unreasonable to suggest that the French Government restricted research of this nature, especially that using AGRS, due to their total dependence on nuclear energy. As a world leader in the technology, France would have a lot to lose if her reputation was damaged by the rendering visible of its radioactive hotspots, if the origin of them was *not* that of RBMK no4.

What is shown within the *Atlas* has been, and will continue to be, crucial in the mitigation of the extended geography of the Chernobyl disaster. What is obscured may not be as important, but the simple fact that it is not a 1:1 representation of the environmental reality created by the RBMK no4, in that it points attention to a specific viewpoint at the expense of others, resulting in the conclusion that it can be classed as a Latourian panorama: a powerful contraption which takes on the challenge of solving the question of staging/representing the totality of a reality by subsuming the micro, meso and macro into one another. In the words of Latour:

> they collect, they frame, they rank, they order, they organise; they are the source of what is meant by a well-ordered zoom. So, no matter how much they trick us, they prepare us for the political task ahead. Through their many clever special effects, they offer a preview of the collective with which they should not be confused. As we now begin to realise, there is always a danger to take the building of those panoramas for the much harder political task of progressively composing the common world. (Latour, 2005, 188).

This concept is applicable to a raft of different entities, and its application here is not without one last disclaimer. The 'special effects' at work are the above mentioned spatial implications of the *Atlas's* findings, the very real and very important actions tasked with safeguarding the general populace from the fallout. However, this necessity of the emergent reality should not be taken as the totality of it. As has been shown, there are always political and economic mechanisms turning the gears of perception behind every articulated viewpoint.

Chapter 6

Risky networks: RMBK no4's role within the scientific controversy over the Linear No-Threshold model of radiological protection

---

An important, but relatively unknown avenue of Chernobyl's network remains. This trajectory of the NPP has endured the passing of time and features nodes of sustained scientific action which sought to construct a new conceptualisation of risk for the impacts of radiation. This chapter will account for the scientific battleground regarding the use of the Linear No-Threshold (LNT) model of radiation protection. Conceptually, this phenomenon draws interesting connections with Beck's Risk Society (1992), his notion of re-modernisation, and Latour's (2003) writings. In essence, it represents an empirical point of contact between the concept of Beck, and the methodology of Latour. For Latour, "A perfect translation of 'risk' is the word *network* in the ANT sense" (2003, 36); the iteration of a 'finalised' risk is the result of a heterogenous, and unexpected maze of connections and relations between human and non-human actors. Thus, akin to a network, a risk features a double movement, a two stage process that incorporates its construction and function. Latour (2013) provides the example of the railroad network to illuminate this conceptual stance, in that the finalised function of the rail network, that is, the transportation of humans (and things) along tracks of metal by non-human vehicles, does not account for the *network* of construction. The constellation of actors, institutions and machinery required to plan, design, apply and actively construct the final ontological rail network (Latour, 2013). It should be noted that this distinction does require certain levels analytical accuracy, or, at least, a delineation of what network is under analysis. C*onstruction* or *purpose,* as the actions of each movement are different. In this instance, two stages of construction shall be accounted for: the construction of LNT's 'risky network', and the creation of its leading competitor.

As mentioned in a previous chapter, this conceptual means of viewing 'a risk' provides a purposeful methodology, one that is lacking within Beck's overarching project. Thus, the highlighted connection between Latour's network and Beck's notion of a risk prepares the ground for the deployment of the ANT toolset. Latour goes one stage further and seeks to utilise this connection to identify material instances which 'prove' the emergence of what Beck describes as 'reflexive modernity', (or re-modernisation for Latour (2003)). For Latour, the benefits of this 'recalibration' of modernity, ignoring the more fundamental differences he has with the meta modernist project, reside in this instance on moving attention away from 'the mainstream', and directing it upon the "discrepancies, cracks, failures and side effects" (Latour, 2003, 46) that are barely visible to the lay public. In so doing, re-modernisation seeks to produce an account of a world that has outgrown the framework of progress.

This is a powerful articulation of Beck's project, and it speaks to his instance that the material outcomes of manufactured risks have outpaced the established systems of protection and insurance (1992). We reside in an era characterised by invasive techno-social developments, or, in other words, the Risk Society. An epoch where complexities increase, and agreement on definitions, regulations and even the ontologies of objects become entangled throughout a host of different domains. This seepage has been a hallmark of this entire project, as this account has shed analytical light upon Chernobyl's travels, or more accurately, RBMK no4's transgressions, across, within and through a number of different domains of reality. This chapter marks its movement through the classical Latourian dilemma associated with the mutation from matter of facts, into state of affairs (1992, 2003, 2013 etc). The subversive philosophical aim of this task is to fill the role of a *never-been-modern* social scientist, relinquishing the mission to instil a master narrative, to instead provide alternative viewpoints engendered by means of empirical analysis. In other words, provide synthesis of a situation that resides within the blindspot "of common ignorance so typical of the pubic sphere" (Latour, 2013, 45).

Taking this into account, what follows is a brief history of the LNT theory – its core premise, and an account of its hegemonic network (prior to the Chernobyl accident) – which will feed into its complicated entanglement with the Chernobyl accident. The two sides of the debate surrounding its validity will be articulated, their key arguments accounted for, and this will be routinely interlaced with an explanation of how the agency from the nuclear non-human provided the initial impulse to engender this scientific polemic. As shall be shown, there is no finalised outcome to this node of action, no master narrative has emerged to dethrone LNT, and, conversely, several works have been published that *further legitimise* the assumptions of LNT. Evidently, this is in direct contrast to the post-Chernobyl movement that has sought to problematise LNT's hegemony status, and it results in a curious back and forth polemic, with both sides of the debate forwarding evidence to support their claims and no clear ontological 'winner'. As will be shown below, LNT is the gold standard of radiological protection, and its position is as close to unmovable as is institutionally possible (Calabrese, 2009, 2013). Thus the movement seeking to replace it will always be swimming against the current. This represents an interesting dynamic, and one that adds to the confusion surrounding the relationship between damage to biological entities from low level radioactive doses and the role RBMK no4 played within this node of action. The agency from the Chernobyl accident produced several new worlds of risk, and in every other instance accounted for within this thesis, the general conceptualisation of 'risk' has increased in severity, heightened the necessary protection measures and directed much more attention to their mitigation. These reconfigurations of risk have been a direct result of the material realities RBMK no4 unleashed upon the globe. The LNT debate is unique as it represents a very rare instance when actors are attempting to decrease the risk associated with a byproduct of the accident, namely low dose radiation. Thus, it could be argued that, due to the host of interested and powerful stakeholders involved, the account of this specific travel of RBMK no4 was destined to be elongated, complex and, ultimately, contradictory.

It should be noted prior to departure that this chapter has been constructed using the principles for scientific study laid out in Latour's *Science in Action* (1987). The reason for using these methods at this stage, rather than continuing with 'vanilla ANT', is centred around the domain of study. Prior to the Chernobyl accident, it could be argued that LNT enjoyed the status of a 'black box' with the scientific disciplines working within radiation protection; however, the impact of the disaster upon its standing has been disruptive. Since the accident, attempts have been made to open the box, and other competing boxes have been built. Thus, an empirical analysis of this polemic, prompted by the Chernobyl disaster, facilitates the study of 'science in action'. The systematic attacks and building of defences, around scientific programs.

6.1 The deliberately conservative radioactive context: an introduction to LNT and Chernobyl's global ranking

This subsection details LNT's network of construction, the various component theories, actors and events that commingled to establish the approach as the gold standard of radiological protection. Since the discovery of radiation the discipline of health physics has sought to articulate practical scientific guidelines for radiation protection standards (Sanders 2009). The production of epistemological systems to quantify the risk associated with ionising radiation and set acceptable levels of exposure for the general public and occupational limits for actors working within industries that feature radionuclide exposure (eg the workers of a NPP or an operator of an x-ray machine). Ever since Roentgen discovered the X-ray in 1895, and Becquerel radioactivity one year later, the guidelines for protection standards have changed repeatedly (Vaiserman 2010). But, at for least four decades after 1972, the underpinnings of these standards have been the linear no-threshold dose-response model (Kathren, 1996), or LNT for short. In 1956, the US National Academy of Sciences Committee (NASC) on Biological Effects of Atomic Radiation Genetics Panel published a comprehensive recommendation regarding the risks associated with ionising radiation, and it states that evaluation should adhere to a linear dose-response model (Calabrese, 2013).

This recommendation represented a paradigm shift within the discipline, as prior, a threshold based dose-response model was regarded as the gold standard within medicine and physiology (Calabrese 2009). In essence, the threshold model stated that under a certain threshold, 100 mSv, the dose should be classed as acute, and as there was no empirical evidence that could prove the appearance of biological damage, regulations were made in accordance. On the other hand, the LNT argues that risk scales perfectly with dose rate, and although the risks are lower at low doses, such levels *still present* unacceptable risks. Thus, there is no threshold dose, and any radioactive dose is classed as potentially risky/harmful. As an aside, at the time, there was no empirical data that emphatically highlighted a causal link between biological damage and acute doses of radiation, therefore, LNT was predicated by estimations, rather than ontological data (Calabrese, 2013).

What is important to highlight at this stage is the role of 'institutions' within LNT's risky network of construction - governmental bureaucracies tasked with setting the protective limits of externalities, with the aim of safeguarding a country's citizens. Professor Edward Calabrese (2005; 2009; 2011; 2013), of the University of Massachusetts (an important actor within the LNT and Hormesis network), has spent his entire career exploring the nature of the dose response in low dose instances, and has written extensively about the origins of the LNT model. Throughout this historical work, the theme of Institutional agency features prominently as he routinely cites appendages of the U.S governmental system as being crucial actors within LNT's network of construction. Two years after the aforementioned advice of the NASC in 1956, the National Committee for Radiation Protection and Measurement (NCRPM) accepted the findings and extended the logic to somatic cells and cancer risk assessment (Calabrese 2011). This represents the first major building block within LNT's radiological prevalence, as soon thereafter several other national and international advisory committees/institutions followed suit (Calabrese 2009).

The power of network thinking frees analysis from individual domains (Latour 2013) and instead promotes an exploration of how the phenomena in question progressed through different domains. The late 1950s features one of the first instances when LNT began to migrate from its scientific origin and seep into politics. The Delaney Amendment, promulgated in 1958, and named after Congressman James Delaney of New York, forbade the addition of agents to food that was known to cause cancer within animals or humans (Huff, 2007). Prior to this amendment, Delaney had met with Dr Wilhelm Hueper, a scientist within the National Cancer Institute (Calabrese 2009). Dr Hueper was a leading expert within environmental and industrial carcinogens, and the meeting between these two representatives of their respected domains provided LNT with the combined political and scientific agency to further its stake for hegemony. The use of Dr Hueper's ideology, philosophy and scientific credentials allowed Delaney to legitimise his amendment within the political domain, and subsequently pass it through the necessary channels. What is important to highlight at this stage is the differences between the Delaney Amendment and the linearity at low-dose methodology - the former was focused upon the food industry and the latter radiological protection. The crucial point of philosophical contact is the insistence on zero to minimal risk exposure. In other words, the Delaney Amendment set the political foundations for this new paradigm of risk assessment within the United States.

After this evental moment, the next significant event within LNT's risky network of construction is found in 1972, arguably the most important year within the entire enterprise. The aforementioned BEAR Committee was renamed the Committee on the Biological Effects of Ionising Radiation (BEIR), and in 1972 it issued its first report (Gottfried & Penn 1996). This report did not attempt to evaluate the shape of the dose-response curve, however it did provide *estimations* of cancer fatalities from low doses, extrapolated from the high dose data of the Japanese atomic bomb survivors. The main conclusion of the report states that:

> If our estimates of risk are too high, the only dangers are those which might derive from excessive caution, such as regulation which might permit greater hazards from other sources to replace the overestimated radiation hazard thus avoided. A more serious error would be to underestimate the effect... We remind all who may use our estimates as a basis for policy decisions that these estimates are an attempt to take into account only known tangible effects of radiation, and that there may well be intangible effects in addition to whose cumulative impacts may be appreciable (NAS/NRC, 1972, 58).

This extract encapsulates the underlying mantra of the LNT model: the overestimation of risk in a bid to provide comprehensive safety precautions. It goes as far as casting cost-benefit calculations as a crude means of assessing safety, and states that if a risk *can* be reduced it must be, even if the cost-benefit is minimal. This report also marks the first major instance when LNT was used as a means of *estimating* cancer deaths, rather than simply being used as a model for radiological protection standards. Granted the two are mutually reinforcing, however, as we shall see, when the approach is used as a means of epistemological projections, scientific disagreement occurs. Today, the digital version of this report resides within the IAEA's website, an interesting inclusion that highlights the report's role within the Agency's adoptions of an LNT framework of radiological protection.

As mentioned above, 1972 was a significant year for LNT's network of construction, predominantly as it featured two important events. The second features the U.S Atomic Energy Commission (AEC), the talismanic Institution within radiological protection within the U.S, and the forerunner of the current Nuclear Regulatory Commission (NRC). A few months after the BEIR report, the AEC introduced the concept of 'as low as practical', otherwise known as ALARA (Krathren, 1996). Fundamental to the implicit logic of this risk mitigating concept was the LNT model. In essence, ALARA built upon the logic of the BEIR report, and moved towards a stance of 'better safe than sorry', when dealing with low-dose radiation. The wider implication of the ALARA programme was the belief that any dose, no matter how small, follows a linear trajectory and therefore has the potential to cause injury, or mutations, within exposed individuals (Gottfried & Penn, 1996). Thus, the deliberatively conservative approach to low-dose radiation had been set, and the following twenty years saw its gradual, and totalising, international adoption. It should be noted that, in 1972, the world had yet to experience a nuclear accident that challenged the concept of 'as low as practical', in that, LNT existed within a scientific vacuum. Chernobyl represents the first instance when vast amounts of low level radiation was dispersed across the general public, and this new phenomenon has led to many questioning if setting risk assessment levels 'as low as practically possible' is still the best way to move forward.

The U.S National Academy of Science has been unwavering in its support of LNT, and still endorses the approach in the twenty-first century. This internationally respected institution represents, arguably, the longest, and most steadfast supporter of the approach. Therefore, the institutions status within LNT risky network of construction, *and* purpose cannot be understated. The list of major scientific bodies that have followed the National Academy of Science in endorsing the LNT is comprehensive, including governmental (and non-governmental) institutions with agency within policy creating processes, and the political realm. In the U.S, the National

Council on Radiation Protection and Measurements (NCRP, 2002), the National Radiation Commission (US NRC, 2006), and the Environmental Protection Agency (US EPA, 2008) continue to use the approach. The Canadian Nuclear Safety Commission (CNSC, 2009), the institution that directly informs the Canadian government of radiological issues, supports its continued use, and the International Commission on Radiation Protection (ICRP, 2006) (based in Canada) echoes these recommendations. The European institutions that back LNT are arguably even more influential, due to the international scope of their agencies. In this instance, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and the International Atomic Energy Agency (IAEA, 2007) argue for the validity of the approach. Thus, two appendages of the United Nations continue to promote an policy of purposeful conservatism (as low as practically possible) when encountering lose-dose radiation.

The appearance and significance of institutions within this network draws connections to Latour's arguments surrounding the renewal of trust within such bodies (Latour 2013). He argues that the time for universal scepticism has passed, and when faced with a phenomenon on a global scale, with high levels of innate technological and scientific controversies, the integrity of institutions should render their accounts/findings/representations as trustworthy. This tangent of Chernobyl's network provides an opportunity to *examine* the advice of Institutions through a scientific controversy. Contrast their airtight discourses with the conflicting and argumentative works of individual scientific actors who stand to challenge the estimations of the approach. The Chernobyl accident provided the spark for this controversy around the validity of the LNT — the polemic is a node of actions engendered within the new world created by the explosion. Over the decades, the LNT has achieved the status of the gold standard of international radiation protection guidelines, so much so that some believe the approach is untouchable (Truta *et al* 2012). The fact that the accident promoted nodes of action which sought to challenge LNT's black box status is further evidence of its potency, and a valuable instance to account for how it has travelled since 1986.

6.2 The global average exposure, and the difficult entanglements with the LNT

It is important to make a distinction between high and low doses of radiation, and in the interests of clarity, high doses are represented by Sieverts (Sv), and low doses are accounted for in microsieverts (mSv) - there are 1000 mSv in 1 Sv. A whole-body dose of more than 5 or 6 Sv is typically lethal (Land 1995), and this would be the upper limit of a 'high' classification. There are not many places on earth where such levels exist, outside of the hearts of nuclear reactors, their irradiated spent fuel, near the epicentre of an atomic explosion, or the Elephant's Foot that resides within the innermost bowels of the ruins of RBMK no4. In other words, dose levels of this magnitude are the epitome of Beck's manufactured nuclear risks, the invisible byproduct of advanced technological hybrids, created through the breaking of nature's strongest bond found within the structure of atoms. Now, the LNT debate does not centre round such levels as it is accepted that exposure to them would cause irretrievable damage to a human's biological vehicle. On the other hand, low level dose rates, and the consequential relationship to risk, are much more ambiguous and therefore open to diverse mediations by the hands of *interested* actors.

Prior to articulating the basic premise of the LNT model, we can take a moment to account for the unavoidable radioactive realities that the passengers of earth currently face. Since its creation in 1955, the United Nations Scientific Committee on the Effects of Atomic Radiation has periodically produced a review of the sources of ionising radiation, and in 2000 it incorporated the Chernobyl accident into its calculations. The report (UNSCEAR, 2000) provides a detailed summation of the global average exposure, and it breaks this figure down into the component parts. It states that natural background sources contribute to 2.4 mSv of the total, inhalation of radon 1.2 mSv, terrestrial gamma rays 0.5 mSv, cosmic rays 0.4 mSv, ingestion 0.3 mSv, diagnostic medical examinations 0.4 mSv, atmospheric nuclear testing 0.005 mSv, the Chernobyl accident 0.002 mSv, and nuclear power production 0.002 mSv. These individual sources contribute to a figure of 5.209 mSv per year as a global average dose rate for each person.

The vast majority of radiation indeed comes from natural sources from materials within the earth's crust, and this figure has remained relatively constant throughout the totality of Homo Sapiens' evolutionary curve. Furthermore, the four largest producers of ionising radiation are natural processes, with only medical examination procedures coming close to achieving similar levels. On the other hand, Chernobyl's contribution to the global average is 200 times smaller than medical examinations, and the accident accounts for 0.03840% of the total dose rate. Difficult questions surrounding the faithful production of risk resonate throughout this chapter (and the thesis in general) and statistics of this nature further complicate proceedings. Chernobyl was routinely deployed as Beck's talisman of nuclear manufactured risks, and in numerous ways he was justified, but when one accounts for the disaster's contribution to the global whole, a number that will decrease year on year (while the others remain constant), it does erode the legitimacy of such a representation. In blunt quantitive terms, Chernobyl's global contribution here is minimal.

I feel that, at this juncture, a moment of self reflection is necessary. As this chapter is being constructed through the lens of Latour's *Science in Action*, the fundamental tenet of this approach surrounding the treatment of 'facts and machines' cannot be ignored. Latour argues that their fate is in the hands of later users and that one should not focus upon the intrinsic quality of a statement, but rather direct attention to the "transformations it undergoes later in the other hands" (Latour, 1987, 59). This format of analysis is a hallmark of all that follows, however, the researcher must never be blind to their own transformation. The above contrasting percentages did not appear in the UNSCEAR 2000 report, but were instead calculated by the researcher, and thus they are translations of the core 'statement'. It would be a stretch to class them as mediations as they merely translate the information into a different format without deformation. However, they do render visible a relationship that was not immediately apparent within the document. My purpose here is to engender a pragmatic context, one that seeks faithfully to represent the ontological reality, devoid of sensationalist or 'external' interests and agencies. Regardless, doing so could be perceived as an attempt to represent the Chernobyl accident, and its impacts, in a less risky manner. Thus, sustained self reflection is an essential component of an ANT scholar during the production of a faithful account of a phenomenon, and I will return to this contradiction in the conclusion.

One may have noticed similar numerical values being deployed throughout this chapter with huge variations between the outcomes. In a previous paragraph, 4 - 5 sv dose rate was attributed to a fatality and 5.2 mSv was found to be the average global rate. Thus, a bit of housekeeping is in order. There are 1000 mSv (millisieverts) in 1 sv (sievert), therefore we can assert that the global average dose is roughly five thousand times lower than a fatal level.

If we aside the fact that the Chernobyl disaster's contribution to the global whole is significantly less than medical diagnostic examinations, it is instructive to return to the UNSWEAR report (2000), and particularly the section dedicated to the dose rates experienced by the liquidators, the Pripyat evacuees, and surrounding population. It states that the average dose for the liquidators was 100 mSv, 30 mSv for the 116,000 evacuated people from inside the Ukrainian exclusion zone, and 10 mSv during the first decade after 26th April, 1986, for the people who continued to reside in the contaminated area. This figure is applicable to both the self-settlers who chose to return to their homes within the 30km zone, and the workers of the town of

Chernobyl. The figure 6.1 is of a self-settler, a group of people who the Soviet Government let return to their homes, as long as they were over 50 years old and promised not to have any more children.

Figure 6.1: A 'self settler' of the Exclusion Zone (source: researcher's own photograph 2015)

There is no reason to doubt these calculations, but, they are averages and thus the final output will be impacted by the lowest and highest inputs. For example Kesminiene et al (2008) state that some liquidators were subjected to 250 mGy absorption rate (250 mSv) in 1986, and between 50 and 100 mGy (50 - 100 mSv) in 1987. This figure is further dwarfed by the levels experienced by the Complex Expedition team as its members routinely worked within areas featuring 200 - 300 roentgens (1865 - 2798 mSv), or between 1.5 and 3 sv (BBC, 1991). As there is no mention of these actors within the UNSWEAR report, the figures regarding the clean-up actors/liquidators should be treated with a dose of critical thought. That being said, these examples are the exception and not the rule, and the vast majority of the liquidators worked outside the reactor hall and never experienced anything close to these levels.

Regardless, the purpose of accounting for these figures is to render visible the levels experienced during the worst nuclear accident imaginable and its subsequent contribution to the global average. I am not trying to claim that they are acceptable, nor welcome. Their inclusion merely creates a scientific rational outlook, a pragmatic means of assessing the meta-risks associated with the accident and radiation in general. The average dose rate the liquidators experienced was 100 times lower than a fatal dose, and these men and women worked within the epicentre of the accident. Furthermore, the average doses experienced within the neighbouring countries was under half that of naturally occurring background radiation. Everyone agrees that Chernobyl was a horrific accident, but when the dose rates are contrasted with natural phenomena, or fatal doses, rather than being viewed in isolation, an argument could be made that the international reaction to the appearance of RBMK no4's unstable atoms was an unfaithful epistemological mediation of the ontological reality.

6.3 Linear no-threshold model: the underlying scientific logic

LNT *assumptions* are rooted within the relationship between dose and risk (Cohen, 2005), or, in other words, the nexus between the ontological reality of ionising radiation and the epistemological negotiations of risk construction. Due to the fact that manufactured radiation is a product of the 20th century, the sciences have had little opportunity to access empirical data surrounding its long-term impacts on the human body. As mentioned briefly in Chapter 5, the use of data from Japanese atomic bomb survivors has generally been considered as the gold standard for estimating cancer risk from radiation (Doss, 2013). This view was due to the exposure being non-selective (children, adults and both sexes were subjected to it), the heterogenous range of doses (from low to high), and, crucially, the continuous performance of systematic monitoring of the survivors' health since the bombs were dropped (Hall & Brenner, 2008). This unique 'case study' has been an essential tool within the production of radiological protection systems/protocols, because epidemiological studies, a quantifiable means of ontological analysis, are the fundamental component when setting said protection standards (Gilbert, 2009). Releases of manufactured radiation upon a large population have, thankfully, been a rarity within the epoch of atomic technologies, and the first event to provide another 'case study' after the two atomic bombs of WW2 was the Chernobyl accident. Due to ambiguity of low dose biological impacts, epidemiologic methods cannot be used in isolation as the data are often conflicting (Jaworowski 1999). Thus, as the sciences could not solely rely on ontological studies they had to incorporate an epistemological system to articulate the risks associated with this phenomenon. The underlying logic of LNT is extrapolation, that is, deducing the risk of low doses through the use of data accrued from high dose case studies (Land 1995) - the atomic bomb victims.

The LNT relationship is predicated upon the proportionality between dose and cancer risk. Tubiana et al (2005) state that the approach is based on one set of data and two hypotheses:

> "(a) The relationship between dose and DNA damage in vivo seems linear from 1 mGy to 100 Gy with use of H2AX foci as a marker for DNA double-strand breaks (DSBs)… (b) each DSB is hypothesised to have the same probability of inducing cell transformation, irrespective of the quality of DSBs present simultaneously in the cell; and (c) each transformed cell is hypothesised to have the same probability of developing into an invasive cancer, irrespective of the dose delivered to the tissue." (2005, 13).

Linearity is king here, and it trumps case specific developments. In essence, the model states that the impacts associated with 1mGy will scale perfectly to 100 Gy, and the same can be said of probability, a risk technician's favourite calculation. Thus, one can begin to identify the connection between high dose data and the extrapolation to low dose. Granted the model is articulated from the 'ground up', conceptualised from low dose to high, but the scientific reality of its articulation was from the 'top down'. What is crucial to recognise at this stage is that LNT states that the deposition of physical energy (ionising radiation) into a biological entity increases carcinogenic risk linearly with an increasing dose, at a 45 degree slope, and that this biological prophecy remains constant irrespective of dose (Averbeck 2009).

The BEIR report of 1972 featured prominently within the previous section, as it was shown to be one of the first instances when an influential governmental institution appropriated the approach and produced guidelines in accordance to its logic. Thus, in a bid to attain a level of scientific accuracy, the information within its pages shall be accounted for, and consequently, the inner workings of the LNT model will become fully illuminated.

In order to ready the foundations, the report accounts for the 'kinetics of mutation', and states that DNA is "organised into larger linear nucleoprotein structures" (NAS/NRC, 1972, 64), and these structures are comprised of a series of triplets of nucleotides. This complementary formation results in the 'ladder like' popular image of a gene. It is argued that mutation occurs when the linearity of DNA's ontological form is disrupted, damaged or added to. Furthermore, the report argues that a more significant class of mutational events arise from breakages within the chromosomes of the nucleotides. This could be caused by an injection of energy into the DNA from an external source: for example, when a person is subjected to a high dose of ionising radiation (Jeggo *et al* 2016). Finally, the report argues that at the very bottom of the range, "it is impossible to define just where a deletion should be considered a point mutation in the gene rather than a chromosome breakage type of mutation. For most of the chromosome rearrangements considered in this context, with low LET irradiation, the frequency of induced rearrangements is proportional to the dose over the dose range of interest. (NAS/NRC, 65).

What must be taken from this extract is the insistence of damage to DNA at low doses, even thought the exact 'type' cannot be identified – lesser mutation or more significant breakage.

By accounting for the different types of damage at both high and low dose ranges, the report has introduced a linear dose-response relationship without any threshold. It goes on to state that if no threshold exists, then "the curve, when extrapolated to lower doses, should intersect the zero-dose ordinate at a value equal to the spontaneous rate" (NAS/NRC, 66). The report uses data from experiments upon mice to conclude that observations are compatible with the above assumption, and that the statistical error is too large for it to be tested with any rigour. Interestingly, the report does not feature sustained calculations that would represent the 'workings' of the approach, nor does it delineate an account of it being used in practice. It appears that its authors expect certain levels of knowledge on its principles. Thus, in order to reassemble such an account, other sources must be explored.

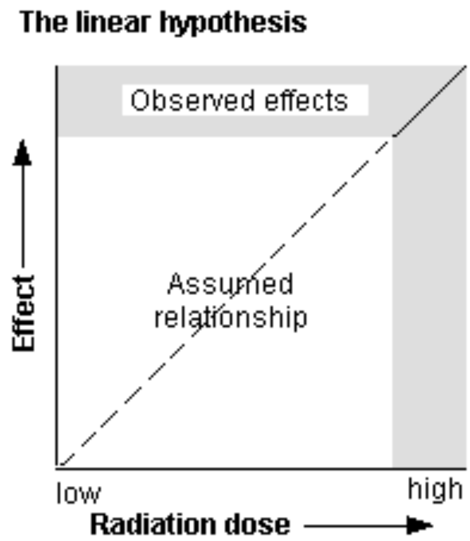

Figure 6.2: Graphical representation of the LNT risk/dose relationship (source: World Nuclear Association, 2016)

Figure 6.2 graphically expresses the relationship between collective dose and the excessive relative risk, and the dotted horizontal line represents zero on the y axis. It should be noted that this is the universal representation of LNT, and the ratio of the relative risk with the amount of dosage is always a constant. This is a fundamental assumption of LNT, that is, that risk can only increase with dose. The area in question, that is the section of the graph where the dosage has sparked contemporary scientific controversy, is below 100 mSv, otherwise known as acute doses. This upper limit of 100 mSv is where the model derives its name, the 'no-threshold' is tasked with countering the claims of the threshold model that stated that a threshold existed at this dosage (Hoel 1998). As we shall see in a later section, some members of the scientific community argue that there is no correlation between the risk of cancer and radiation below 100 mSv, that is, no causal relationship. LNT on the other hand argues the relative risk of cancer is proportional to radiation dose, and it increases linearly from zero. This assumption therefore assumes that the processes for cancer production are the same at low and high doses (Tubiana *et al* 2006).

In terms of fundamental calculations, LNT uses the aforementioned concept of 'collective doses' and the correlating excess relative risk (Cohen 2012). Sanderson (2009) provides an example to highlight how these calculations are performed. He uses the ICPR (2006) annual public dose limit of 1mSv, and then uses this figure to identify the excess risk by means of the NCRP Report No. 115, in this instance, it is 5 x 10^-5 (0r 0.000005) and he subsequently multiplies it with the population size, 1x 10^6 (1,000,000), and this provides a collective dose of 50 Sv. He goes on to state that the collective dose is then used to calculate excess cancer deaths by means of simple linear extraction. In this example, a population of 1,000,000 multiplied by the collective dose of Sv year^-1 (0.02) would contribute to 20,000 excess cancer deaths per years. This simple mathematical sequences represents the core of the LNT approach, and it has been utilised numerous times to calculate prospective deaths. One of the most famous studies was conducted by Brenner *et al* (2003), when they used the collective dose of CT scans, 10 - 20 mSv, and the population of the United States, to argue that 1.5 - 2% of all cancers in the country are attributable to the use of CT scans.

In essence, this is a two stage process: the first entails the discovery of the individual dose. This value is then applied to the NCRP's iteration of LNT's relationship between dose and excess relative risk to identify the probability matrix. This number is then multiplied by the population of the affected area, and this produces the collective dose. The second stage then uses this collective dose and multiplies it with the population once again, and the end figure is the estimation of cancer deaths. There are no finer details to the inner workings of LNT, the entire programme of purposeful conservatism is founded upon these calculations.

When taking all of this into consideration, it seems logical to class LNT as a discourse of risk (Beck, 1992), the 'accepted' rhetoric of radiological risks at low doses. For Beck, the concept of risk is a means of rendering visible a possible future reality, and that once a possible reality has come to pass, the discourse representing a risk ceases to apply (Beck 2000). As mentioned in a chapter 2, this totalising account features several empirical blindspots, especially within the area of nuclear engineering (this shall be accounted for in the following chapter). However, when it comes to LNT, his argument is semi-correct. As we shall see in the following sections, the material appearance of a massive nuclear accident drew scientific critical gazes onto the assumptions of LNT, consequently questioning its continued validity. Granted LNT never 'predicted' a nuclear accident, but its primary purpose was to set guidelines in the wake of a dispersion of low dose radiation, a phenomenon which had yet to pass during its construction. Thus, its relevance, utilisation and black box status is fundamentally linked to manufactured risks of this nature.

6.4 The linear no-threshold model and Chernobyl: a case of science in action and the unintentional eroding of a blackbox

What must be accounted for at this stage is the output created when LNT's calculations are applied on a population scale, as this nexus represents the introduction of RBMK no4's agency. Once a statistical output has been created, and an estimation of excess cancer deaths published, the resulting agency is powerful and potentially very damaging. This reasoning brings us to a very important and influential publication, one that calculated the global impacts of the Chernobyl accident by means of the LNT model. The significance of this article to the network cannot be understated as its statistical output was deployed as a means of attaching ready (and sensationalist) understandings to the complex and multifaceted risks associated with the accident. In other words, the article represents the construction of a statistically possible ontological outcome for this catastrophic manufactured risk.

In 1988, Dr Lynn Anspaugh of the University of Utah, Professor Marvin Goldman of the University of California and Professor Robert Caitlin published *The Global Impact of the Chernobyl Reactor Accident* in the very influential journal *Science*. The paper itself has attracted a large network dually due to its usefulness for LNT proponents and its 'controversial' nature for the approach's detractors. The significance of the texts can be accounted for in an examination of its citation network. GoogleScholar highlights that the article has been cited 321 times, and it has become one of the foundational building blocks of an argument's fortifications, as well as the target of assault for those who do not agree with the LNT assumption. In other words, it is both revered and reviled, and in the face of the Fukushima accident, its longevity has been extended by several decades.

Prior to detailing the text's finer details, an exploration of its network must be conducted in order to render visible the actors drawn to it. In order to assess the nature of the publications citing this article, the 28 years since the article was published were split into two, one from 1988 to 2000, and 2001 to 2016. The reasoning behind this was to attempt to identity any 'breakages' within the discourse, that is, an evolution of the tone of article citing this text. In essence, as medical technology has progressed/developed, the arguments against the continued use of LNT have increased in number, thus, this chronological segregating will allow this account to provide an empirical backbone to this statement. Methodologically, the articles citing Anspaugh *et al* (1988) were ranked in order of their publication's 'influence', in accordance with Bergstrom's system (2007), and the number of times the article had been cited. This dual process renders visible the scope of the networks of these texts, as-well-as the non-direct reach of Anspaugh *et al* (1988).

The first period saw the article cited 103 times, roughly one third of the overall total. There is a notable correlation between the influence of the journals and the number of citations within the top 20 cited articles within this period (excluding books). The most influential publication that positively cites Anspaugh *et al* (1988), is *Human minisatellite mutation rate after the Chernobyl accident (*Dubrova *et al* 1996), published in Nature (15.88 influence points) and cited 399 times; this article accounts for the increased number of mutations within the heavily populated areas of the Mogilev district of Belarus. It references the statistical output of Anspaugh *et al (*1988) as a legitimate possible outcome of the accident. Interestingly, the majority of the article's authors are either Ukrainian or Russian, and the lead author, Professor Dubrova was once a member of the NI Vavilov Institute of General Genetics in Moscow. He published this article two years after leaving Russia for The University of Leicester.

The second article within this period was again published in Nature, and has been cited 230 times. *Fitness loss and Germline mutations in barn swallow breeding in Chernobyl* (Ellegren *et al* 1997) uses Anspaugh *et al* (1988) as a means of providing a human context of the accident's potential damage. The authors are all Swedish (the only European country to register a radioactive release in the days after the accident), and this publication represents the most influential 'merging' of human orientated LNT statistical outputs, with research conducted upon the wildlife.

The third publication was published within the Annals of Internal Medicine and was cited 254 times. *Thyroid cancer: a lethal endocrine neoplasm* (Robbins *et al* 1991) is one of the few articles not directly researching impacts of the Chernobyl accident, but inevitably mentions the accident due to the type of cancer involved. Its reference of Anspaugh *et al* (1988) is somewhat critical, however it predominantly uses it to highlight the number of potential cancer cases produced by environmental radiation. This publication is interesting as it highlights the scope of both the accident and the article under analysis, in that both appear throughout a generic publication that researches thyroid cancer. Chernobyl has become synonymous with this type of cancer, and within this period Anspaugh *et al* (1988) had become the predominant means of legitimising an argument 'supporting' the damaging material by-products of the accident.

As mentioned above, 103 articles citing Anspaugh *et al (*1988) were published within this period. 74% of these articles directly referenced the Chernobyl accident within their title, and 90% of this total utilised the reference without critical comment. That is, used its findings as a means of validating and vindicating their own arguments. In other words, within this period, the publication was predominantly used as a means of fortifying arguments.

The second period, between 2001 and 2016 saw the article cited 218 times, over double the amount of the first. This total is inflated by a large percentage of publications focused upon the Fukushima accident of 2011. Granted this influx of work conducted upon the most recent major nuclear accident skews the Chernobyl relevant findings, however it does highlight the continued use of the enacted systems within Anspaugh *et al* (1988). By far the most influential text within this period is *Life exposed: biological citizens after Chernobyl* (Petryna, 2013), a book cited 954 times. The author is an anthropologist and she puts forth bold arguments around the accidents biological impacts. She goes as far as claiming that "More than 3.5 million people in Ukraine alone, not to mention many citizens of surrounding countries, are still suffering the effects." (Petryna, 2013, 3). As the author is an anthropologist, she relies on scientific references to vindicate her social science arguments, and the outputs of Anspaugh *et al* (1988) feature throughout this book. It is not surprising to find a publication of this nature utilising the statistical outputs of LNT without much critical insight into the polemic surrounding its usage; regardless, this example highlights how useful the article has become within the discourse seeking to demonise the nuclear industry.

The second and third publications of note in this period are two books, *Fundamentals of ecotoxicology* (Newman 2009) and *Sustainable energy: choosing among options* (Tester 2005). These two textbooks deal with the intricacies of environmental toxicology and the energy market. The former adopts a mediated outlook on Anspaugh *et al* (1988), citing increasing complexities and the inability of health physics to either prove or disprove mutations under 100 mSv. Within the latter's chapter on nuclear energy, the spectre of the Chernobyl accident is routinely deployed, and the statistical output of the LNT framework used as a means of highlighting the potential damage to human health. It should be noted that the inclusion of this article within any publication is valid. As mentioned above, the LNT is the bedrock of the world's international radiological protection system, it is difficult to imagine such a system being in place without it. However, the new emergence of evidence that contradicts the model's assumptions *should,* at the very least, force academics to treat its statistical outputs with a modicum of critical thought. As we shall see, there is a body of work that critiques Anspaugh *et al* (1988), however, my analysis has found that the majority of publications citing the article use it in a positive manner.

Within the 218 articles citing Anspaugh *et al* (1988), 51% directly referenced Chernobyl, and 68% used the reference without sustained critical reflection. This figure is smaller than the percentage within the first period, however it is not a massive change. Well over half of the publications still use the publication as a means of validating an argument. This majority could be explained by the aforementioned 'gold standard' role LNT plays within radiological protection, however this is mere speculation. Regardless, this empirical exploration of the article's publication network has uncovered that the 20th Century has seen a small movement of academics begin to question the LNT's outputs. Thus, this article should be viewed as an evental moment; it dealt with the impacts of the world's worst nuclear accident, and it represents the first time LNT was deployed onto a massive population base. In essence, although its outputs are epistemological in nature, they allude to an ontological reality, one where tens of thousands of people could die.

As previously mentioned, research of this nature marks the fusing of LNT assumptions with data on the scale of a country's population. The authors divided their analysis between the entire population of the affected regions, and categorised it into to the most notable 'cancer sites' — spaces that were subjected to higher doses. In order to identify these spatialites, and the techniques needed to make a connection between excessive risk and carcinogenic impacts, the authors used three respected reports as a means of equipping their analysis with the statistical data required to calculate the expected rate of cancers.

> the U.S Congress-mandated National Institute of Health report on the development of radio epidemiological tables, the Nuclear Regulatory Commission NUREG report on the 'summed

> health' effects models for nuclear power plant accidence-consequence analysis... and the recent UNSCEAR report on the genetic and somatic effects of ionising radiation. (1988, 151).

They argued that these three reports are consistent due to their similar conclusions/results. The use of these reports, produced and published by the US government, Harvard University, and the United Nations, represents the keystone within their defences. What they go on to claim could have been impactful upon the nuclear industry, the Soviet Union, and the physical and mental wellbeing of the people who resided in the affected territories. Thus, the authors had to base their expected cancer calculations on strong foundations, and the use of these three respected reports achieved that goal. If anyone sought to question their findings, they had the ability to 'call on' these reports for analytical and empirical back up; or, in Latourian terms, they could "bring friends in" (Latour, 1988, 31)

The geography of the article is 'global' in nature, with the authors routinely deploying concepts such as "the world's citizenry". In order empirically to construct a 'global sense', the authors include the populations of 40 countries in their analysis (including East and West Germany), ranging from every European state to Asia and the United States. The statistical workings of LNT have the ability to condense diverse spatialities into unified figures as-well-as provide segmented analysis, the nature, or scale, of the output is dependent on how the user has orientated its 'demographical' structure. Thus, the spatial component of the approach is at the whim of the actor at the helm. As this article is tasked with accounting for the 'global' implications of the radioactive spread, the meta outputs will be the cumulation of each country's estimation of cancer deaths. Thus leading to the production of a more 'sensationalist' number. Furthermore, there is a temporal element within this article, in that the calculations allude to a 50 year radiation dose; this is a generalised account of how each radionuclide decays over time, with no assessment of each space's deposition/dose.

When seeking to explore the minutiae of the Anspaugh *et al's* (1988) methods, a section (that is less than one page of A4 paper) contains an excellent example of the LNTs' hegemonic status within health physics, and the international radiological protection systems of governance. In essence, the authors provide no explanation of the approach's finer details, and instead state that:

> For latent health effects such as fatal cancers and genetic disorders, the scientific community has reached general consensus on a model derived from a linear-quadratic

> dose relation for low dose... It is assumed that no threshold dose exists below which there is no risk, although the data do not eliminate the possibility of zero risk a low doses. (Anspaugh *et al* 1988, 1515).

This lack of methodological elaboration is a common theme within the LNT discourse: the provision of generalised accounts, as opposed to reassembling the intricacies of the approach/calculations. Throughout this thesis, numerous scientific domains have been explored, and the principles of their methods accounted. Several have shown disputes, or controversies, during the creation of a black boxed consensus. However, LNT's journey to a hegemonic powerhouse has seen no major debates, and this is epitomised by the routine simplified explanations within publication's methods sections — similar to Anspaugh *el al* (1988) example. As we shall see, it took an event of truly unseen damage to begin to shake the foundations of this approach. It required a new world, with original ontological parameters to challenge the question of its continued validity.

In terms of Anspaugh *el al* (1988) results, the team calculated a 50 year radiation-dose for the affected areas, and the exposure rate for a number of radionuclides was accounted for, including C-137, the disposition measurements for which were taken from national and World Health Organisation reports (another block in their arguments' defences). The temporal element of the article's analysis involved radioactive decay calculations, and the identification of the decreasing curve, over the 50 years. Over this period, the authors accounted for the three primary cancers created by exposure to ionising radiation: leukaemia, bone and thyroid. The underlying inclusion of these excess solid cancers is also linked to the source material used, and the absolute risk projections associated with them. Due to LNT's status, its tenets reside within institutional discourses, and these texts are used as the guidelines for research projects. In this instance, the probability matrix within the aforementioned NUREG report was used as the baseline statistical inputs.

This is another interesting facet of LNT's network of *purpose,* in that its unified formation is so intrinsically 'black boxed' that it is stored and disseminated by institutions. There is no plurality, there is one system, a singular means of calculating radiological risk at every dose. The probability matrix for a dose rate has a universally accepted numerical representative, and these relationships provide the statistical bedrock for any research project seeking to estimate the excess cancer instances of a phenomenon. This is not to say that there are no *competing* approaches - the contemporary model of hormesis shall be covered in the following section - however, within LNT, there is no deviation from the central reasoning and logic.

The Anspaugh *el al's* (1988) final means of calculation involved the multiplication of the varying dose rates within each country with the aforementioned risk projections/coefficients, and the output of this calculation is then multiplied by the population of the area. When each country's excess cancer deaths were computed, and each added together, the final figure of 53,400 possible deaths was attributed to the Chernobyl disaster (Anspaugh et al 1988).

As a brief aside, prior to an evaluation of this figure, it must be noted that the authors explicitly state that their findings are estimates, and that "one of the most misunderstood concepts encountered in the analysis is the way in which probabilistic or stochastic risks are perceived and presented" (Anspaugh et al 1988, 1518). They highlighted that their statistical output are increments of a probabilistic distribution, and thus not a degree of certainty as "frequently reported in the media" (1988, 1518). At the time of publication, several newspaper headlines wielded the 'fifty thousand dead' figure with unabashed sensationalism, and thus it could be argued that this is a mediation of the original article - thus alluding to Latour's second rule of researching scientific discourse. However, the use of the article's statistical output is devoid of translation, for the use of said figure is merely transporting information without deformation, but also without acknowledging the summary paragraphs that detailed the 'estimation' nature of the entire piece is moot. In essence, the final section represents the final block within the authors' defences, the failsafe, perhaps. Due to the geopolitical context of the period, and the ever present agency of the ruined reactor, the authors, three intelligent and credible scientists, must have been aware of the 'potential impact' of an article of this orientation. They were writing about one of the greatest 'controversies' of the late-twentieth century, an "icon of destruction" to use Beck's (1992) terminology. The incorporation of a section that, qualified, even undermines their entire research project effectively produced a degree of separation from 'responsibility', providing a means of 'excusal' in the face of external appropriation of the statistical outputs. Therefore, akin to the European Commission's *Atlas for the Deposition of C137*, this article should be viewed as a Latourian panorama, a restrictive window into the representation of reality, one fused with the subjective interests of the actors responsible for its creation.

As mentioned above, the global dose rate accredited to the Chernobyl accident was 0.0046 mSv, a figure over double the figure quoted within the UNSCEAR report (2000) referenced above. This increase could be explained by the 12 year gap between the two publications; regardless, the dose rate in question is minimal at best (especially when considering the average background and medical examination dose rates). A paradox resides within these calculations, in that they are both useful and inaccurate: useful to the stakeholders with interests that could be furthered by public fear, negative opinions towards the nuclear industry or geopolitical leverage. And inaccurate on a scientific level as they are nothing more than (mere) estimates.

I will conclude this section with some arithmetic. Once again, we return to the UNSCEAR figures (I am aware of the similarity in tactics to the Anspaugh et al, in that I am using a 'well respected' publication to fortify my argument) and pose a question: if 0.0046 mSv global dose rate from Chernobyl is to account for 53,400 deaths, and medical examinations procedures contribute 0.4 mSv, some one hundred times the amount of that attributed to Chernobyl at its highest, will that dose rate cause 5,340,000 cancer deaths across the world? As the global average natural dose rate is 2.4 mSv — over five hundred times larger the 0.0046 mSv of Chernobyl — should this figure not contribute to over 26 million deaths every year if we are to accept and extend the LNT core assumption? These figures may seem outlandish and unbelievable, but they are merely the result of an extension of logic the LNT model, the standard for radiological risk systems, to the other sources of global ionising radiation.

Relentless pragmatism is the hallmark of this chapter, with the production of an informed context the goal. Granted such an account can be produced thirty years after the event with the aid of hindsight, but the desire to construct a faithful representation of risk should always be of primary importance. As mentioned above, LNT has become a fundamental appendage of the risk industry, a willing and capable accomplice within the formation of epistemological constructs tasked with representing the invisible and, for some, frightening process of radiation. As we shall see in the following section, an unwelcome byproduct of this linear calculation has been within the realm of 'risk perception', and the latter's impacts upon the populations coated with C137 has been much more damaging than the unstable atoms.

6.5 Risk perception, LNT and Chernobyl: the case of radiophobia

The term 'radiophobia' has been used within the former Soviet union to describe the psychological distress experienced by the liquidators (Pastel, 2002). And although the term has the hallmarks of being a clinical classification, the discipline of psychiatry has not recognised it.

> The concern about large doses is obviously justified. However, the fear of small doses, such as those absorbed from the Chernobyl fallout by the inhabitants of central and western Europe, is about as justified as the fear that an atmospheric temperature of 20C may be hazardous because, at 200C, one can easily get third degree burns - or the fear that sipping

> a glass of claret is harmful because gulping down a gallon of grain alcohol is fatal (Jaworowski, 1999, 24)

The above quotation, from one of LNT's most persistent detractors, highlights *his* take on the ontological reality of low doses of radiation, and alludes to an unwelcome outcome of LNT calculations of risk – the perception that even minute doses of radiation can be harmful.

In order to fully grasp the intricacies of a 'phobia', the Diagnostic and Statistical Manual of Mental Disorders (DSM) 5th Edition (2013) provides several criteria for the diagnosis of phobia:

> "(A) Marked fear or anxiety about a specific object or situation. (B) The phobic object or situation almost always provokes immediate fear or anxiety. (C) The phobic object or situation is actively avoided or endured with intense fear or anxiety. (D) The fear or anxiety is out of proportion to the actual danger… (F) The fear, anxiety, or avoidance causes clinically significant distress or impairment in social, occupational, or other important areas of functioning." (2013, 135).

Criteria A and D are of key relevance here; that is, the avoidance of the phobic stimuli and the knowledge that the fear is of proportion to the actual danger. As radiation is invisible, the possibility of avoidance is only gained when one is equipped with a Geiger counter (and situated knowledge of how to operationalise its readings), or 'top down' guidelines of the risks/ depositions present within a landscape. Thus, the fear of radiation is fundamentally linked to risk perception, and, therefore, the process of production of risk itself as this is the primary means of a population's gaining knowledge of its presence.

The nexus between proportionality and the actual danger is of key relevance to LNT. The DSM states that "individuals with specific phobia often recognise their reactions to be disproportionate, they tend to overestimate the dangers in/of their feared situations, and thus the judgement of being out of proportion is made by the clinician." (2013, 137). When dealing with radiation, the ability to recognise one's disproportionate fear is granted through knowledge of the carcinogenic and radiological sciences. Both disciplines feature dense and exclusionary texts which reside within academic journals hidden behind paywalls. The combination of high knowledge barriers and monetary requirements renders this ability out of the reach of many, and thus the lay public must rely on 'top down' delineation of the existence of radiation, dose rates, and the subsequent risks. This relationship taps into the realms of the ontological and the epistemological, as opportunities for mediation, be it purposeful or subconscious, are ever present.

Cultural approaches to risk (eg Douglas 1992, Adams 1995, Puckett et al 2015) have stressed the significance of factors such as trust within institutions delineating the risks, the perceived fairness in exposure to risk, and people's intrinsic views as influences in how collectives formulate their different opinions on what constitutes a risk. Constructivist approaches place significance upon the subjective negotiations between individual actors and risk discourses, especially within the era of 'the risk society', as the majority of manufactured risks require situated knowledge to fully comprehend their dangers. Thus, when risk technicians utilise a model of radiological prevention that delineates a reality where even the most minute amount of radiation is dangerous, this relationship, arguably, becomes asymmetrical, and irrational fears take hold. For Jaworowski, this process of risk *overestimation*, by means of LNT, has led to the irrational fear of low level radiation – radiophobia – a psychological impact of RBMK no4.

The final part of this empirical journey returns to late August, 1986, four months after the accident. At this time, the IAEA held a private conference between the East and West to discuss the event, the first international summit tasked with technically discussing the accident. Dr Valery Legasov, the deputy director of the Kurchatov Institute, and the man responsible for the entire clean-up operation (Meshkati 2007), prepared a report for the IAEA. The 388 page document was, for the Soviet Union, uncharacteristically detailed and honest, and it claimed that roughly 45,000 cancer deaths could be attributed to Chernobyl. This figure was reached by means of the LNT model (Patterson 1986). In an interview in the 1990s Hans Blix, the former Head of the IAEA, reflected upon this figure and the model in general. He stated that,

> "These are theoretical calculations, based upon the Hiroshima model, that you say that if you have a set of radioactivity, you know from Hiroshima that some many will die from it, and if you increase it by ten fold, you assume that it will be a ten fold increase. Well that is the calculation, this is not exact and nor empiric." (Blix 1990).

This statement, and personal reflections on a significance conference, by one of the most influential actors within Chernobyl's network, renders visible the desire, or agency, to tackle the unnecessary fear of radiation by the IAEA. By flat out refusing these Soviet figures, the IAEA was attempting to mitigate the public's risk perception process, and inject a modicum of scientific reality into the charged moment in history. As will be obvious by this point, the Anspaugh et al article of 1988, which used the same model, arguably damaged this process.

As an aside, the resistance of the IAEA publicly to acknowledge the statistical outputs of Dr Legasov produces a confusing position. As mentioned in a previous section, the IAEA are proponents of LNT, therefore one would assume the institution would vindicate such 'findings'. Without access to the actors responsible for making this executive decision, there is no way of uncovering *why* it was made. Regardless, it does highlight the two ways LNT can be used: setting regulatory parameters, and statistical model of projection.

There is a relatively large body of literature on radiophobia and the linkages to the Chernobyl accident, with many claiming that the most damaging effects of the accident upon the affected populations has been psychological (Drottz-Sjoberg & Persson 1993; Girard & Dubreuil, 1996; Jaworowski; 1999; Zykova 2007). Goraczko & Latek (1999) argue that the need for better education is clear, and this should be underpinned by a pragmatic radiological model for safety guidelines. As without such a move, this unwelcome and damaging dynamic between lay actors, risk technicians, and the material presence of low dose radiation will persist. The body of work exploring radiophobia suggests that the current model of radiological protection is in fact causing unintentional harm to the very people it seeks to protect. In essence, this forms a connection between health physics, clinical psychology and the general public. Thus, one could tentatively conclude that the actors who know the most, with regards to atomic science and technology, fear the least, and those who know the least, fear the most.

6.6 Enter hormesis: the contradicting counter argument of LNT

I shall conclude this chapter with a look at the competing carcinogenic model that contradicts the assumptions of LNT. It should be noted at the outset that the event that sparked a counter movement to the LNT model, and open its black box, was the Chernobyl disaster. The model previously existed in an epistemological vacuum, safe from material reality as no event has prompted its deployment on a large scale. Obviously, the Chernobyl accident changed that.

In short, the term hormesis is derived from the Greek meaning 'to excite' (Henschler 2006) and the process entails an adaptive response by biological organisms to external invaders (Sanders 2009). For ionising radiation, it is "interpreted to be adaptation to background radiation exposures, combined with adaptations to higher radiation exposures dependent on metabolic protection from the array of other abiotic stresses in the environment" (Hooker et al, 2004, 443). The process depicts the human body as a reflective entity, capable of strengthening its evolutionary defences (to ever-present background radiation) to deal with an increase in environmental exposures. Thus, this model envisions the fleshy units of humanity as able to withstand and resistant low dose radiation, as opposed to LNT which, due to its total reliance on the Hiroshima data, states that we are totally at the mercy of any form of radiation. In other words, hormesis takes note of the fact that humanity has evolved within a crucible of radiation. It is literally everywhere, and if one was to leave our blue spaceship, and go outside of the protective shield provided by magnetosphere, the dose increases exponentially. Background radiation from the stars and the earth has been an ever-present throughout humanity's evolution, and the hormesis hypothesis argues that our bodies have developed innate biological defences over the millennia to protect us from its unstable energy (at low levels). In order to visualise the change in logic, a dose/risk graph is best placed to highlight the differences, and similarities, between LNT and hormesis. In a previous section, figure 2 delineated LNT's trajectory, not surprisingly in an arrow straight line.

Figure 6.3 represents the underlying logic of hormesis, and the primary departure from LNT is the area referred to as an acute dose, that is, under, in this instance 200 mSv. Above that range the trajectory is identical to LNT due to scientific consensus regarding the damage to biological entities at high doses. The most interesting aspect of this graph is the line below the risk coefficient, thus alluding to a beneficial component to low dose radiation (Mattson & Calabrese 2009). This is obviously in direct contrast to LNT, which argues that any dose of radiation is dangerous.

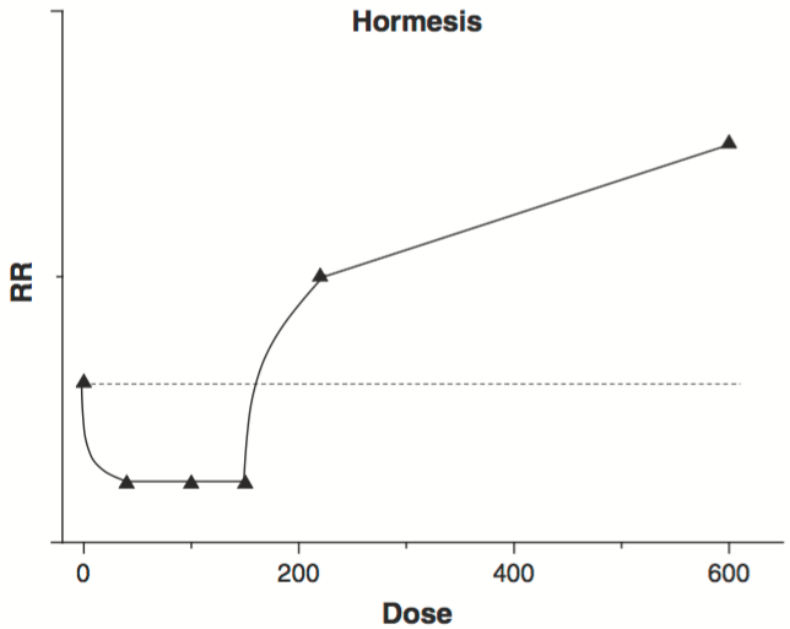

Figure 6.3: graphical delineation of Hormesis logic. (source: Sanderson 2009)

Feinendegen (2005, 159) characterises the mood of the change by grounding his argument through the use of an accepted reality, "that cellular responses to low values of absorbed doses of ionising radiation are not readily predictable by extrapolation of responses observed at high doses". This statement, some 19 years after the accident, highlights the shift within some parts of health physics away from LNT, due to the fact that extrapolation, and linearity assumptions, simply do not align with the empirical data. This unassuming argument is a challenge to the black box status of the LNT model. In essence, this move sees a reversal in logic. As mentioned previously, LNT is based on 'top down' extrapolation, from high dose data to low dose - or, conceptually speaking, 'meta'ing downwardly towards the material'. Now, health physics still agrees that radiation induced DNA damage and genomic instability increases with absorbed dose (Feinendengen, 2015). However the relationship is no longer linear, rather, the trajectory is curved. Thus, at menial and low dose rates, the probability of engendering cancers is minimal.

The aforementioned Professor Calabrese is the talisman of the hormesis movement, and due to his extensive writings upon LNT's trajectory to the radiological gold standard, he is a well informed actor within this competing network. Outside of charting the history of LNT he has written extensively about the qualities of the approach (Calabrese & Ricci 2011, Calabrese 2011, Calabrese 2012a, Calabrese 2012b, Calabrese 2013), and won numerous grants to research the underlying logic. His publication history started in 1986, and over the years his research interests have evolved, yet, the notion of risk assessment has been a mainstay. Evidence of this is found within the defence of his Doctoral thesis, titled *A single exposure to a carcinogen can cause cancer. Documentation, limitations and implications for risk assessment.* (1989). Since 1998 he has, firstly, tested the hypothesis, and secondly championed it, as "a generalised biological phenomenon" (Calabrese & Baldwin, 1998, 357). Despite these efforts from a world renown scientist, LNT is still used as the foundations of radiological protection systems. Thus, one must pose the unavoidable question of why?

At this juncture, it is useful to consider how governmental institutions 'frame' risk, in this instance the Health and Safety Executive (HSE) of the UK. Within its report upon societal concerns about risk (2002), three framing devices for risks are provided, each pertaining to the heterogeneous melee of risks a society encounters. These categories are directly perceivable risks, those only perceivable with the help of science, and virtual risks - the second and third are of relevance here. Institutions akin to the HSE reply heavily on scientific advice, and when the sciences have reached a consensus regarding a specific risk, it is then classed within the second category. Virtual risks are delineated risks that "range from unconfirmed scientific hypotheses derived within conventional science, through speculations by 'alternative specialists', popular fears, superstitions, to theological speculations… the risks that conventional science cannot convincingly confirm or refute cause the greatest difficulties for regulators" (HSE, 2002, 3). As mentioned several times throughout this chapter, LNT is the gold standard of health physics for radiological protection, even to this day. Thus, environmental radiation, and the risk it engenders, would comfortably reside within the second category. However, arguably, with the emergence of the hormesis hypothesis, and the empirical studies that highlight its existence, risks from low-dose radiation should have migrated into the realms of 'virtual risks'. In the past twenty years, there have been more publications seeking to disprove LNT's assumptions than arguing for its continued use. Yet the approach's position holds steadfast.

Scientific controversies are complex, multifaceted, and at times contradictory. In the interests of producing an impartial account, the other side of the argument must be elaborated upon, primarily as it helps answer the above question of why has LNT remains the gold standard. Unfortunately for the proponents of hormesis, a vast body of empirical data has shown alarming mutations within humans and wildlife, post April 26th 1986. Jensen *et al* (1995) identified an increase in the frequency of glycophorin within human subjects, Santoro *et al* (2000) discovered evidence of gene rearrangement that has produced increases in thyroid cancer, and Weinberg *et al* (1997) accounted for mutations within the offspring of the liquidators of the NPP. This is just a tiny cross section of the publications that claim empirical evidence of genetic mutations caused by low dose radiation, originating from Chernobyl. Yet, contradictions are everywhere, as numerous pieces of research vigorously claim that such mutations are not increasing as a result of the radioactive dispersion. For example, Lima *et al* (2004) argue that child thyroid cancer cases have not increased within the affected areas, and Thomas *et al* (2002) find contradictory results within their own study, concluding that due to the passing of time "the overall HPRT deletion spectrum gives little evidence of a radiation signature." (2002, 184). It is essential to consider all of these works that account for the damage caused by the accident.

Furthermore, in the past five years, a body of empirical research has been conducted that actively contradicts the hypothesis of hormesis. For example Ozasa *et al* (2012) found no evidence of hormesis occurring within Japanese atomic bomb survivors, and in fact concluded that the data highlighted "the risk of all causes of death was positively associated with radiation dose." (Ozasa *et al* 2012, 230), thus, their results were directly in line with the LNT assumptions. One year after this study, Metz-Flamant *et al* (2013) discovered a significant relationship between low-doses (a mean of 22.5 mSv) and myeloid leukaemia, which prompted them to conclude that the LNT EES relationship with that dose was accurate. The research participants were French nuclear workers (France is the only country on Earth that has contradicting institutional opinions on LNT), and therefore subject to that dose on a daily basis. 2015 has seen several studies of a similar nature, in scope, subjects of analysis and aligning conclusions. Richardson *et al* (2015) explored the risk of cancer from occupational exposures within British, French and the United States nuclear industries. This was a large study with 308,297 participants, and the authors concluded that "Although high dose rate exposures are thought to be more dangerous than low dose rates exposures, the risk per unit of radiation dose for cancer among radiation workers was similar to estimates derived from studies of Japanese bomb survivors. Quantifying the cancer risks associated with protracted radiation exposures can help strengthen the foundations for radiation protection standards." (Richardson, 2015, 1141). It therefore appears that this study claims to have empirically discovered a link between low dose exposures and excess cancers, thus validating LNT's risk/dose matrix. The final sentence of the extract alludes to the author's objective, that is, scientifically quantifying the estimations and assumptions of LNT.

Finally, Spycher et al (2015) explored the relationship between background radiation and childhood cancers, in an attempt to uncover a causal linkage. The authors made the bold conclusion that background radiation may contribute towards the risk of cancer in children. This is in direct contradiction to the principles of hormesis that claims a positive biological outcome from low-dose exposures, the epitome of which is the eternal bombardment of energy from our planet's surface, and the celestial domain. The findings from all of these studies directly contradict the hormesis hypothesis, thus clouding the debate, and miring it further within the realms of uncertainty.

The previous section detailed the arguments that claim that psychological impacts have been one of the most harmful consequence of the Chernobyl accident, however this account would be asymmetrical if it did not account for the works of reputable scientists that argue *for* a connection between low-dose exposures and biological mutations. The discursive ordering of the chapter, with the psychological arguments being presented ahead of those of health physics, was chosen based upon the contradictions within the latter. The controversy over LNT, the conflicting works/opinions on the actors on each side of the debate has created a, for want of a better term, messy landscape. Even with the steadfast support of powerful national and international institutions tasked with creating protection systems, the continued and contradicting debate surrounding what actually happens to biological organisms when exposed to low-doses, renders the phenomena as unpredictable. This is in direct contrast to the consensus regarding the psychological impacts radiation can have upon a population.

In light of these contradictions, and the inability of health physics to universally identify empirical damage, or repair, with an acceptable degree of accuracy, it seems that the innate logic of LNT is beneficial. In essence, if we are not confident, then a purposefully conservative regulation system is worthwhile, and indeed necessary. The key issue, or problem, is found when the approach is when it is used to 'estimate', or predict possible empirical outcomes. This is the point when safeguards transform into soothsayers, and with it, vast numbers of potential deaths based on models. Thus, in this context, LNT lives a double life, one practical, intent on protection in light of scientific ignorance, and the other, as a utensil for estimation, by means of scientific assumptions. On the other hand, hormesis, for some, should become the replacement for LNT, however, it has yet to come close to building enough support to challenge the titan of LNT. The Chernobyl disaster provided the agency to begin to question LNT, yet, not even its agency is powerful enough to alter the gold standard.

Regardless, this inceptive movement towards hormesis, and the subsequent change in scientific logic marks a significant movement within the radiological scientific community, and should be viewed as an empowering paradigm shift for the lay public. Vulnerability is a hallmark of the risk society (Beck 1992), suggesting the inability of a single actor to have agency with reference to phenomena that impact upon them. Manufactured risks in the scope of Chernobyl are the epitome of this condition, and the mediated representation of the risks is a node of action which needs to be addressed. The work on horemesis, and the subsequent construction of defences and networks to support its new 'gold standard' claims could be viewed as a move in this direction. It can also be argued that the LNT model feeds the fires of vulnerability without conclusive empirical to support the assumptions. As previously stated, this chapter is tasked with providing a pragmatic context. It represents the point in this thesis where the assumed risks, the taken-for-granted and a scientific by product of the accident are set against an account of the material. The contradictory and, at times, confusing discourse, that which reinforces LNT, and the those that seek to dismantle its hegemonic position. The production of a faithful account of a network is an unwavering necessity for an ANT scholar, without this quest, the output reverts into the realms of fiction and mediation. What has been constructed within this chapter is a relatively unknown avenue of risk within Chernobyl's network, one of the only times that said risks have sought to be 'decreased' in the name of argued empirical accuracy. It is not attempting to claim that the accident was not absolutely horrific, rather it is merely promoting another scientific outlook upon the radioactive dispersion and the epistemological construction of risks.

6.7 Conclusion

As stated in the introduction to this chapter, this example of RBMK no4 ‘travelling’ is ultimately ambiguous in nature. It is possible to render visible the nuclear non-human’s agency within the little-known scientific polemic, but the extent to which it has actively altered the course of the debate is more difficult to uncover. LNT is a powerhouse, it would be difficult to imagine an international system of radiological protection without the approach’s implementation and spread throughout the powerful, standard defining institutions of the world. Thus, when viewed in this light, it may not come as a surprise to find that the counter movement has been unsuccessful in its attempt to dethrone LNT, even in light of the influx of empirical ‘opportunities’ engendered by RBMK no4, and a host of research delineating results contrary to LNT’s assumptions. Radiation is a *difficult* phenomena: it obscures its existence from human senses, it requires a diverse portfolio of knowledge and instrumentations to register and measure its presence, and as the science’s understanding of it is in relative infancy, we are unable to make totalising assertions about its impacts upon biological organisms.

This is a fitting concluding sentiment to the empirical heart of this thesis, the realisation of the countless ambiguities created in the wake of the event of the Chernobyl accident. From actions that sought to actually ascertain what process caused the explosion, to the confusion surrounding the ‘intact reactor’, and the panoramic view of the Caesium-137 deposition over Europe, each of the empirical chapters has accounted for nodes of actions engendered by the travelling of RBMK no4’s agency, and each features ambiguous elements. This is not surprising as an event of this magnitude is so disruptive, and creates so many new worlds in its wake, that the attracted network of diverse *interested parties* is bound to produce confusion, deviation and ambiguities. As mentioned above, the empirical chapters of this thesis have stayed true to Latourian principles, and faithfully allowed the actors to reassemble the network of RBMK no4 as they experienced it. Thus, the end product is at times conflicting, but any other representation would become unfaithful.

Chapter 7

Returning to the site: a decade of change or stagnation?

Throughout the empirical core of this thesis, the analysis has routinely moved away from the site of the Chernobyl facility, both in space and time. Chapter 3 explicitly detailed the ontology of the object of RBMK no4, and the sequence of events that led to the accident, but from that point onwards the accounted nodes of actions have been staged in increasingly distant spaces and times. This literal and chronological, horizontal movement, in effect, accounts for how this object has travelled outwardly from the site in northern Ukraine, since April 26th 1986. In this concluding chapter, attention returns to the reactor site as a means of capping the research, and will feature a discussion on how it has evolved since the researchers's first and last visits to the site. This spatial return is fused with a sustained reflection on what the research has achieved, the successes and failures of the conceptual framework, and a more general discussion about the site of the reactor facility. This section attempts to provide a concise answer the central research – how has RBMK no4 traveled? – and, additionally, considers the extent to which the nuclear nonhuman, and its physical landscape, have now been 'settled'. In a bid to colour this discussion, two last nodes of action shall be interwoven into this, somewhat personal, process of self critique: two fundamentally important series of actions that could be classed as the epitome of the 'lessons learned' from of the accident; two instances that fuse risk and practice within the ontological form of RBMK no4, with both seeking to return the object, and the site, to a mode of stabilisation.

7.1 The juxtapositions of the Zone of Alienation: the curious guarded emptiness of Pripyat

The site of the Zone of Alienation is a perplexing place. Its classification as the site of a level 7 nuclear incident, and a landscape of heightened levels of radiation sealed off from the outside world, evokes images of a baron wasteland of crumbling buildings, devoid of human interactions. In many instances, these assumptions are correct, but, when one is exposed to the normal operating procedures of the reactor facility, can also be misguided. It is indeed useful to think of the Zone as a collection of smaller sites. As mentioned in Chapter 1, the Zone is split into two officially recognised areas, the 10km and 30km Zones, but even within these spatial confines, the site is multifaceted. Pripyat and the reactor facility reside within the 10km zone; both have been affected by RBMK no4, yet the two have lead very different lives since 1986.

Chapter 1 reassembled my first trip to the Zone in 2009, and the account was coloured by pictures taken during my last visitation. The majority of my time, on both occasions, was spent within the confines of the 10km zone, and in 2015, I returned to several of the Pripyat landmarks previously visited as an Urban Explorer, albeit now in the format of an official tour. As recalled in Chapter 1, the only space I visited during my first trip was Pripyat, due to the city's importance within Urban Exploration circles. My encounter with the city during my recent excursion to the Zone was an ultimately depressing experience. It featured none of the excitement, danger and wonderment of my first exploration, with these engaging emotions replaced with sadness and healthy doses of guilt. As I wandered around the city's empty boulevards and crumbling buildings with the tour guide, recreating several of my favoured highlights from my first trip, I felt guilty for participating in the industry that has turned Pripyat, the once proud Atomgrad, into a tourist attraction. This is not a slight of the tour company, which was professional and informative, but is more a reflection on what Pripyat has come to mean: a 'bucket list' excursion to many, a ghost town to most, and a veritable hotspot of radiation to all.

The material landscape of Pripyat — that is, its human made built environment — has seen very little change since I first set foot in the city. The buildings are a little greyer, more windows have been smashed, and the once vibrant red paint of the ferris wheel has continued its regression into a rusted brown. The two trips were almost a decade apart, and I was initially surprised to witness this lack of 'movement' within the city's material makeup. I wasn't expecting freshly painted walls, but I did expect something different, or perhaps *new,* within the ruination of the buildings. To be sure, 1960's Soviet architectural standards are not renowned for their structural integrity, particularly within a modernist inspired, purpose built settlement, but Pripyat's monolithic flats and community buildings have been, in many cases, reluctant to relinquish their minimalistic charm. Regardless, the biggest surprise of my most recent trip was the vegetation's *relentless* reclamation of the space.

This visit was in late September, yet the trees still clung to their greenery, and the smaller shrubbery rendered some large pathways inaccessible. When walking through certain areas of the city, particularly the region north of the Cultural Palace, it is easy to forget that one is even in a city as the density of the foliage is, at times, unbelievable. From the main doorway of one of the high-rise flats, it is difficult to see its neighbouring tower through the foliage, which can be no more than 20 meters away. Some of the roads of the city have trees sprouting through the concrete, and the main courtyard outside of the Cultural Palace has experienced similar instances of biological reclamation. As mentioned in Chapter 1, today, Pripyat is more of a forest than city, and the only means to view its cityscape is from the roof of some of its tallest buildings. Only when atop of one of these structures does the scale of the city reveal itself to an intrepid explorer. I am unsure how long Pripyat will withstand the onslaught of erosion by greenery, wind and water. It owed its existence to the power station, and with the demise of the facility's usefulness, and the extremely remote nature of its geographical placement within Ukraine, the city serves no purpose to anyone, other than 'disaster tourists', and the people who go places they are not supposed to go.

Schatski's (2002) notion of the site forms an integral part of this research's conceptual backbone. As covered in Chapter 2, when the reactor facility (and the Duga 3 complex) was operating as designed, the site of Chernobyl can be readily identifiable by the internal shared logic of its material landscape. Pripyat was built for the nuclear power station, its material structures designed to house, feed, entertain and educate the carers (and their families) of the reactors. Yet with its fleshy residents long since evacuated, militarised operations ceased (eg the launchpad for the helicopter sorties covered in Chapter 4) and the abolition of electricity production, what role does Pripyat now play within the site of the Chernobyl facility?

It is a difficult question to answer. When viewed from the outside, through an 'uneducated lens', the Zone is a geographical blackhole – a mysterious and dangerous space that spawned one of humanity's worst ever accidents. I have been asked countless times about the dangers of visiting the zone, and most of the people asking seem to regard the space as some kind of mutant infested hell-scape entirely outside and beyond human control. This may be a byproduct of the combination of the cultural industry's delineations of the accident, the radiation, and the inaccessibility of the scientific discourses that account for the *real* dangers of the site. Even a terrible movie has greater scope to permeate throughout the social consciousness than an informative academic journal, hidden behind exclusionary knowledge and pay barriers. The reality of the site could not be further from such negative imaginaries. Granted, my initial excursion featured a somewhat *advantageous* Governmental official, and a scene that would not be out of place within the *Fallout* video game franchise, but I could still identify the regimented nature of the Zone. The large armed guard population, the tense inspection of our paperwork, and the orders to be back at the 30km main entrance by a specific time; these are not indicators of a lawless site.

As covered in Chapter 1, during my most recent trip to Ukraine we passed through the 'official' entrance to Pripyat (a small facility featuring a road block, guard post, and, as usual, an armed military guardsman). Throughout this trip I was routinely surprised by these normal regulatory procedures, as they were such a contrast to my initial exploration of the site. I found myself perpetually asking why Pripyat was guarded? Yes, behind this small barrier lies an *entire* city, but it is nothing more than a decaying shell. Everything of value has been either stolen or removed, and, as far as I can tell, the site did not have any militaristic importance (outside of its temporary role within the initial cleanup operation). The levels of radiation within the Zone, particularly on the main road networks, are in fact now lower than in most European capital cities, but the tour guide informed me that any worker within the zone is paid a substantial 'bonus' to do so – a form of danger payment for their services. Thus, the guardsman, who likely sits idle for 95% of his shift, was being employed, and paid at an inflated rate, to 'guard' a ghost city.

It should be noted that this guarding tactic is a hallmark of the Zone. Duga 3, the mammoth radar complex, and its purpose built town (Pripyat 2), resides a few kms away (as the crow flies) from the power plant, and it is neither signposted, nor easily reachable. One must travel tiny backroads for around 30 minutes to reach it, yet; when the tour bus arrived, we were greeted by three armed guards (and two exceptionally well trained German Shepherds wearing adorable, Ukrainian military branded, dog body armour). During the tour of the compound, the guide told me that Duga 3 was, arguably, the most secretive of all Soviet Cold War facilities, but today, nothing of real value is left. The installation's control room would have resembled something akin to the bridge of the Starship Enterprise, but it has been completely stripped of its computing innards, leaving nothing but their empty steel housing frames. Again, I found myself asking why this remote and inaccessible part of the zone was so heavily guarded? I could list more instances where the tour bus was greeted by armed guards, demanding paperwork prior to letting us into a forgotten space, but these two will suffice.

Upon reflection, this militaristic insistence on guarding these spaces seems almost paradoxical, especially when one considers how difficult it is to gain access to the Zone through the main entrance. As unusual as it may appear on the surface, the Pripyat guard post, and, by extension, the guard network spread throughout the zone highlights the role of these forgotten spaces within the site of the Zone. Other than the reactor facility, the human-built landscape of the site has not been fundamentally changed by human hands. It has been coated in radioactive nuclides, and vast amounts of top soil have been removed, but structurally speaking, the Zone is the same as it was before to the accident. Pripyat was once the stage of countless human interactions, mundane daily activities that imbued its concrete structures with purpose and meaning. It hosted the reactors's carers; and, as they commuted the short distance to the power station, they sustained the link between the purpose built city and the four mammoth fission machines. In other words, they performed the internal logic of the site through this short journey and their workplace activities. Now, 3 decades later, the material logic of the site remains — that is, the purposeful placement of objects and buildings in a pattern designed, ultimately, to produce electricity — but its fleshy inhabitants do not. As a result, a new performance is played out.

For want of a better term, Pripyat is now a constellation of objects, both big and small, that have to be babysat: a once vibrant, self legitimising cityscape, that has been reduced to an empty shell that, apparently, needs constant supervision. The exact reason why it must be under supervision is unclear, but as my first Urban Explorer trip revealed, this guarding ethos appears to be rather shallow. We spent roughly 16 hours in Pripyat, wandered round the majority of the city, spent the night in an abandoned flat, and yet the only people we came across were would-be-raiders. Furthermore, the fact that these men had managed to gain entry into the Zone, presumably without official permission, suggests limits to the guarding of the city.

At one point, 50,000 people performed the material logic of this space within the site, but now the only permeant actor is the guardsman at the gate. Metaphorically speaking, Pripyat has become the appendix of the site; no readily identifiable use to the system, but one that nestles neatly into its material form. Its placement within the 10km zone renders its future use *extremely* unlikely, and the city's unfortunate future will continue to see it excelling as one of the world's premier time capsules. Other than requiring guarding, Pripyat has no productive role within the site of the zone. It is almost as if it simply does not exist anymore. Granted, some research has been conducted within the city's streets, but the vast majority of academic, international, and political attention has been paid to the other significant structure within the 10km zone.

This focus is understandable, due to the unwieldy nature of the reactor facility, and the difficulties of 'settling' it post-accident, and the following section will feature one final exploration of its significance and role within the site. One of the successes of this research has been its steadfast insistence on grounding the analysis within techno-engineering discourses, and a byproduct has hence been the minimal attention placed on Pripyat. The majority of the research's objects of analysis have been in a constant state of flux, both physically and metaphorically. Pripyat featured an intensive moment of change, but once this epoch concluded, the city stagnated. I believe it is fitting to spend a moment reflecting upon the city, particularly as its mysterious allure prompted this Urban Explorer down the academic rabbit hole, but this is indeed where the *real* significance of the space ends. Pripyat owed its very existence to the 4 RBMKs: without the agency of these machines dictating the daily actions of the city's residents, its concrete structures became useless, or, perhaps even lifeless.

A hallmark of this project has been the insistence that the nuclear non-human, RBMK no4, is markedly different from other, non-sentient manufactured products of our collectives. In that, it *forced* humans to act in a manner that could not be ignored. As a result, its significance should, arguably, be elevated *above* human existence. This type of object, powerful in terms of agency and uncontrollably destructive in its materiality, thankfully, is not a common occurrence, and this reflective account of Pripyat creates a constructive contrast: one that highlights the difference between 'normal objects' and nuclear non-humans. If humans had vacated the reactor facility in a similar manner as experienced by Pripyat, more 'destructive potentiality' could have erupted from the building's walls. In essence, the reactor facility retains its fundamental role within the site, with or without human attention/occupation/participation. In terms of physical size, Pripyat dwarfs the reactor facility, but to this day the rectangular building still commands respect and attention from human actors, while Pripyat is nothing more than a reminder of how devastating a nuclear non-human can be to our way of life.

7.2 The surprising daily reality of the Chernobyl nuclear power station, and the new importance of the town called Chernobyl

At the outset of this project, I did not expect to gain access to the reactor facility. I had never seen any pictures of the interior, and had not heard of any tour companies offering the chance to explore the innards of the world's most (in)famous power station. Thus, to my delight, I was informed that Solo Tour East could gain access (for a price). Our tour lasted two days, and the excursion inside the reactor facility took up the majority of the second and final day. I had never been inside a nuclear power plant, and so I had no idea what to expect. I knew that the facility was operated until the year 2000; and, with the new containment project under construction, I expected to see a few employees, but the reality was a surprise.

The main entrance resides in the eastern side of the building, the opposite end to RBMK no4. I was instructed not to take any photographs of the entrance (for reasons that were never fully explained), and from the outside the building is similar to any ageing industrial complex. As the tour bus arrived, I was flummoxed to see a full carpark, with several vehicles parked on grass verges. As anticipated, the bus was stopped at a guard station, our papers inspected, and we were ushered into the building by two armed personnel. We passed through a row of dosimeters and then stopped at a line of metal detectors, accompanied by several more armed guards. This inspection was the most intense of the trip. Our passports were assessed and photocopied, mugshots taken, our fingerprints were digitally scanned and a comprehensively invasive body 'pat down' was performed. Furthermore, the guards of the power plant seemed to be a private militia. They wore different uniforms to the guardsmen positioned around the Zone, their body armour looked significantly more advanced, and they carried modified AN-94 rifles (weapons used by the Russian special forces), a notable upgrade, both in terms of technology and price, to the 'normal' guard's short stock AK-47s.

It was at this point that the reality of the facility revealed itself. The sheer number of people walking about was completely, for want of a better term, shocking. Men and women in suits conversing on the move, scientists in traditional Soviet white lab coats pouring over stacks of paper, and labourers moving large boxes. During the initial entrance inspection, at least 40 people passed through the hallway, and, as we moved throughout the building, countless more personnel passed us. At no point did it *feel* like a decommissioned nuclear power station, one that had experienced a catastrophic malfunction. It felt like a normal working environment, with only the dosimeters and armed guards portraying differently. Several of the facility's more mundane spaces reinforced this feeling. The tour visited a fully operational canteen within the confines of the reactor facility – a huge building serving food that I had never eaten before, operated by a large kitchen staff, and is a space that could accommodate several hundred customers at a time. Furthermore, just to the right of the main entrance stood a large smoking shelter, presumably erected in the years following the accident. When we were leaving the facility after the tour, roughly 100 people were crammed into the small space, in a scene no different from those played out at any large commercial/industrial place of work. I do not think I am over-exaggerating in claiming that, without prior knowledge of the accident, or the timeless aesthetic of the Sarcophagus of Western side of the building, one would struggle to identify the turmoil that the space has experienced over the years. Even the makeshift wall that separates unit 4 from the rest of the building appears as if it was part of the original design, with only the small shrine/memorial to the control room operators, giving some kind of indication of the challenging history endured by the facility.

The sheer number of people working in the facility was unexpected to say the least. I knew several thousand people worked within the confines of the Zone (Mould 2000), but I had assumed that the majority of them were construction workers, tasked with finishing the new containment project. The tour guide told me that over 1000 people still work within the reactor facility, but I could not easily ascertain what these employees are actually doing there. It has been 16 years since unit 1 was taken offline, and its fuel 'settled', literally years ago, so I struggle to hazard a guess as to why such a large, skilled workforce is needed on a daily basis. Regardless, one of the missions of this research has been to uncover 'little-known' aspects of the accident, areas of engineering and physics that were only understood by the experts tasked with actively participating within RBMK no4's network. Some may find the tone and content of these works 'surprising', as some of them are in contrast to the generalised beliefs surrounding the accident, and radiation in general. It is safe to say that witnessing the extensive staffing of the reactor facility, for me, was the biggest jolt of the entire project.

Outside of my personal surprise, this staffing system highlights just how difficult it has been to 'settle' the site, and has interesting repercussions for Schatzki's (2002) notion of the site. As mentioned above, the reactor facility has undergone widespread material change over the years, namely due to the explosions of April 1986, but also due to more technically subtle transitions, which will be covered in due course. To gain a fuller understanding of how the site has evolved over the years, one has to take a short excursion outside of the 10km zone, into the town of Chernobyl.

The traditional Jewish settlement of Chernobyl resides within the 30km zone, but was spared a large radioactive coating due to the wind direction during the days that followed the explosions. The town itself is traditionally Russian, and markedly different from the modernist inspired architecture of Pripyat. Chernobyl is evidently now the main population hub of the zone, with the majority of its daily workforce findings residence within its rows of diminutive flats. The town has everything one has come to expect from a modern settlement: two supermarkets, several pubs, a community hall, a magnificent historical church, institutional buildings, an impressive number of lovely stray dogs, and outstanding wifi. Our tour group stayed in Chernobyl in a small, recently built hotel, which had a fully stocked bar and restaurant. Nothing overly fancy, but still a pleasant place to stay.

This geographical movement of power plant-associated human actors from Pripyat to Chernobyl highlights the main shift experienced by the site of the Zone. As stated in the previous section, Pripyat's material form remains essentially just as it was when the site was functioning as designed, but without its fleshy inhabitants, the city is now rendered useless to the site. It is now a mere collection of objects, without sustained human coexistence – a burden to the zone authority. The town of Chernobyl had limited use for the reactor facility prior to the explosion, being merely the closest 'established' settlement to the construction site of the reactor facility (and Pripyat). Today, it is the arguably one of the most important spaces to the site. Without its flats and community services, the Zone's huge workforce would have nowhere to stay. That is, these human actors would not be able to commute to the reactor facility, thus performing the amended material logic of the site. The reactor's electricity production days are over, but, as was disclosed during my most recent trip, these mammoth nuclear nonhumans still require notable amounts of skilled human action, for one reason or another. RBMK no4 will always be the problem child, an intensively radioactive object that will require monitoring by future generations, but the once normally functioning reactor brethren still pull thousands of people to their material form on a daily basis. Arguably, since the closure of the reactor facility in 2000, the site has had no output, not in the traditional sense. In the ten days following the explosion, it spewed a radioactive hyperobject across huge sways of Europe; and, as the empirical chapters of this research have highlighted, this seepage should be viewed as the most significant 'output' of the site. Thus, the output of the site of the zone has evolved over the years, and the material placement of its human components altered, but, crucially, the draw of the reactor facility remains, and the daily performance of its slightly radioactive actors continues.

A tenet of Schatzki's notion of the site is its ability to resist spatial bounding, as it focuses upon how humans and non-humans spark relations. This insistence can, logistically speaking, be fantastically expansive, but also methodologically unruly/impractical. The Zone is, unavoidably, a spatially bounded space, and akin to the layered nature of matryoshka dolls, it features an internal spatial segment (the 30km and 10km zones). Thus, I believe it would be a mistake not to see the Zone-as-a-site; in that, when attention returns to its material landscape, the researcher must spatially bind its outer limits.

It should be noted that this is an exception to the rule. This entire project has explored how RBMK no4 has travelled, how the site has travelled; that is, accounting for how the site has permeated throughout a host of spheres of reality, physically traveling around the world. Yet, when seeking to reflect upon, and to give insights into how the Zone-as-a-site has evolved over the years, one must stay within the bureaucratic circumference of 'the Zone of Alienation'. When viewed through this limiting lens, the zone is a time capsule in places, intensely radioactive in others, but also the space of 'normal' working/residential practices. The site of the Zone somehow manages to be paradoxical, and yet its material logic, the intricate interplay between the nuclear nonhumans and their fleshy counterparts, still makes sense. Prior to the accident, full families inhabited the site, and as a result, the interactions that it staged were more diverse, and mundane. Today, outside of the self-settlers (covered in Chapter 6), everyone present within the site is there to fulfil a purpose, a role, an action. Arguably, when thoughts turn away from the reactor facility and focus predominantly on the human element of the zone, the more pragmatic actions/placement of these residents represents the largest shift experienced within the Zone-as-a-site.

These past two subsections have provided a moment of reflection, and attempted to identity any change within the zone between my first and last visits. Now, two final nodes of engineering and scientific action must be approached, as both have resulted in vitally important alterations to the material form of the zone. It is fitting to close this these with these final two examples as their nature is in keeping with the research's techno-engineering interests, and both represent the most valuable augmentations made at the site since 1986. The first sought to right the engineering wrongs of the RBMK design ethos, and the second is the international mission to settle the site finally, for good.

7.3 Augmenting Soviet nuclear non-humans in wake of RBMK no4's agency.

> Valuable lessons can be learned from incidents and accidents, as was demonstrated after the accident at Three Mile Island nuclear power plant in the United States of America in 1979, when far reaching follow-up actions were taken to minimise the risk of a recurrence and to improve procedures for accident management. The accident at Chernobyl demonstrated that the lessons from the Three Mile Island accident had not been acted upon in the USSR: in particular, the importance of systematic evaluation of operating experience; the need to strengthen the on-site technical and management capability, including improved operator training; and the importance of the man-machine interface. Hans Blix, Director General of IAEA. (INSAG 1992, 3)

As mentioned above, this research has sought to render visible aspects of the Chernobyl accident that were not 'mainstream news worthy'; that is, obscure scientific and engineering practices that were, for want of a better term, extremely important to the safeguarding of humans and machinery. The above quotation is from Hans Blix, the former Director General of the IAEA, and he highlights, arguably, the most important aspect of any post-accident period, the lessons that must be learned in order to mitigate the risk of a repeat occurrence. Such lessons are hence the invaluable 'silver lining' of a massive nuclear accident, the instances when the entire industry can assess technical, engineering, physics and human protocol standards in an attempt to increase safety and to mitigate risk. As can be seen from the above quotation, it is the opinion of the head of the IAEA that the Soviet Union did not learn any lessons from the Three Mile Island accident in the United States.

As covered in Chapter 3, the RBMK reactor was the pinnacle of the Soviet nuclear industry, and consequently, several other facilities utilised this type of unit. In fact, a total of 5 facilities operated this type of reactor: Chernobyl, Ingalina in Lithuania, Kursk in western Russia, Leningrad and the Smolensk facility. Across these five nuclear power plants, a total of 17 RBMKs were constructed, with 11 still in operation in 2016 (World Nuclear Association, 2016), predominantly in the Kursk, Leningrad and Smolensk facilities.

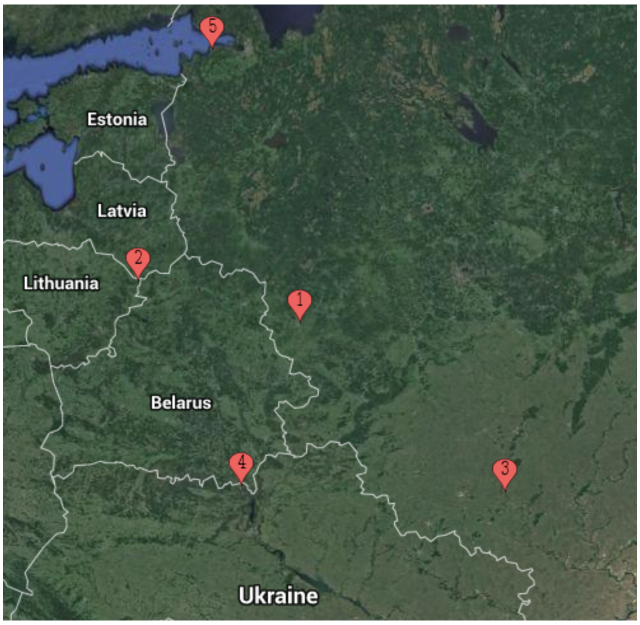

Figure 7.1 Geographical placement of RBMK nuclear power plants. (source: GoogleMaps)

Figure 7.1 delineates the geographical network of RBMK facilities: the first pin identifies the Smolensk NPP, the second Ingalina NPP, the third Kursk NPP, the fourth Chernobyl, and the fifth the Leningrad NPP. All of these facilities feature a similar, if not identical, internal material logic to the site of Chernobyl. In that they were built in remote locations, with each having their own purpose built Atomgrad to house the workforces. As was explosively highlighted by unit 4 of the Chernobyl facility, and the detailed account of its ontology/innate material deficiencies within Chapter 3, the risk of a critical malfunction within the cores of these nuclear non-humans in their original guise is a very real possibility. This risk, for obvious reasons, was an untenable one with which to live, especially after the international community witnessed the unprecedented disruption and human toll of the Chernobyl accident. Thus, something had to be done in a bid to counter the deficiencies of these monster machines, a programme that would cross the 'Iron Curtain' and form an international technical forum, the first of its kind for the predominantly secretive realm of state-produced nuclear technology.

In 1990, four years after the accident, and at the request of the member states of central and eastern Europe, the IAEA initiated the Extra Budgetary Program (EBP) on the safety of WWER and RBMK Nuclear Power Plants (EBP). This expansive node of bureaucratic, scientific and engineering action, one that involved skilled and experienced human actors, was tasked with evaluating the risk posed by the continued use of the Soviet fleet of nuclear reactors, its creation clearly a direct result of the Chernobyl accident. Specifically, the EBP's objectives were:

> 1. to identify safety shortcomings in design and operation of WWER and RBMK NPPs, either as deviations from IAEA standards and international practices or from operating experience, as safety issues to evaluate the safety significance of these deficiencies with respect to their impact on the defence in depth of the plants;
>
> 2. to establish international consensus on priorities for safety improvements;
>
> 3. to provide assistance in the review of the completeness and adequacy of safety improvement programmes with respect to IAEA recommendations;
>
> 4. to undertake specific studies of unresolved topical safety issues. (EBP 1999, 9)

Four interrelated meta-objectives were thereby distilled into focused action and, ultimately, physical change the sites that comprise the network of Soviet RBMK nuclear non-humans. The most interesting aspect of these objectives is the creation of international consensus regarding the priorities for safety improvements, and also the concept of 'defence in depth' at nuclear power plants. At the time, the former had never been attempted due to the militaristic nature of nuclear technology and the tensions of the Cold War. The latter refers to the IAEA risk mitigation philosophy, and it still forms the backbone for all reactor safety standards (INSAG, 1997). The IAEA delineates its foundational principles thus"

> To compensate for potential human and mechanical failures, a defence-in-depth concept is implemented, centred on several levels of protection including successive barriers preventing the release of radioactive material to the environment. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment from harm in the case these barriers are not fully effective. (INSAG 1999, 1

The defence in depth philosophy is a twofold process: the first is to prevent accidents, and the second, if prevention fails, to limit their potential consequences and to prevent unwelcome evolution into a more serious condition (Carnino & Gasparini 2002). The philosophy was articulated in the INSAG 3 (1988) report, two years after the Chernobyl accident. RBMK no4 is perpetually used as the exemplar of the worst accident imaginable throughout the INSAG series, and the material spectre that emanates powerful enough agency to force the nuclear industry to search for maximum defence in-depth for any nuclear non-human. This is a fascinating travel of the accident; that is, the articulation of a system designed to guard against the risk of another malfunction of this nature, and the routine use of RBMK no4 as the ontological validation of this process.

Logistically speaking, it is useful to think of the 'defence-in-depth' philosophy, the object of a reactor, and its cocoon material systems as an onion. The reactor vessel itself is the centre of the metaphorical vegetable and the material levels of defence are the successive layers wrapped tightly around the core. If an accident were to manifest itself within the centre, each layer would act as a barrier tasked with containing the malfunction, and the outermost skin of the onion represents the final layer between the hazardous material and the wider environment. The RBMK had a very poor defence-in-depth rating, one that would never pass contemporary risk standards (INSAG 1997), and one of the primary goals of the EBP was to increase this rating through a series of material retrofittings.

Interestingly, the EBP was initially set up to assess the Soviet designed WWER type of reactor and not the RBMK. This somewhat surprising fact highlights the severity of the dent RBMK no4 put into the confidence in Soviet nuclear engineering. The WWER bears little resemblance to the RBMK — due to its use of light-water as a moderator and cooling system it is more in line with the PWR ethos of the United States nuclear industry. Regardless, the IAEA member states which depended on the unit were influenced enough by the agency of the accident that they requested technical assistance/assessment from the world's leading nuclear authority. This is not the place to detail the intricacies of this part of the EBP, but what must be recognised is that this large international programme was initiated to assess a totally different type of nuclear non-human to the one that blew up on 1986. In other words, the material network of suspect Soviet nuclear non-humans was expanded to incorporate another product of their nuclear industry — a veritable travel of RBMK no4.

1991 saw the extension of the EBP to the RBMK, and the year also saw the fall of the Soviet Union (Dunlop 1993). It does not appear to be a coincidence that Russia only asked the international community for assistance with its flagship reactor after the fall of its old political system. Regardless, in 1993, two years after the initial request, the first safety mission took place within the Smolensk nuclear power plant, and work began on RBMK no4's nuclear non-human brethren.

In total, four safety missions took place at facilities operating RBMKs (IAEA 1996), with 23 missions to WWER facilities; while 27 nodes of intensive human action focused upon a diverse cross-section of the Soviet reactor fleet, tasked with assessing and evaluating the risk of their material form. The key areas of study on the RBMK fleet were the reactor core (reactivity coefficient), component integrity, instrumentation/control, safety and support systems, internal and external hazards, accident analysis, and finally, operational safety (EBP 1999): a comprehensive list of integral material and human components for the operational lifecycle of the fleet. Each of these areas had a specific cast of international experts charged with their assessment, a diverse group with each individual being world leading experts in their chosen field (EBP 1999; INSAG 1999).

These actors heralded from Canada, Finland, France, Germany, Italy, Japan, Spain, Sweden, Switzerland, the United Kingdom, the United States, and ten IAEA secretariats. Frustratingly, there are no acknowledgements, or listings, of these actors' names, anywhere. Thus, they are left as nameless entities, imperatively important and informed cogs in the larger machine tasked with identifying, assessing, evaluating, recommending and, ultimately, creating international consensus on the safety requirements of machines with massive destructive potentiality. This omission speaks to Hull's (2012) account of the varying ways in which anthropology has explored bureaucratic documents, most notably in this case the processes through which they are constructed. He states that, "Discursive logics, concepts, norms and social relations can account for classification schemes, the criteria for bureaucratic determinations of what sort of person or thing fits within them" (2012, 259). Thus, during the process of creation, the bureaucratic structure can closely integrate regimes of control, dually with regards to the individual subjects upon whom the document/discourse is impacting, and also, crucially in this instance, the actors tasked with constructing it. There is no way to 'explain' the anonymity given to these acts without the addition of a redundant layer of epistemological reasoning over the facts. Regardless, the omission of the actors' names provides an interesting insight into the workings of the EBP, and the IAEA more generally. An artefact depicting the actors of a safety missions (to Smolensk on the 7th - 18th of June 1993) is a single photograph found within an article of the IAEA's bulletin series (Lederman 1996). Figure 7.2 is the eerie snapshot of this large group of actors, the human components of this particular node of action.

As an aside, another interesting omission from the final report of the EBP is the safety mission to the Chernobyl facility in 1994. The mission appears in the meta-itinerary, yet no details are provided regarding the works completed. Anatolij Nosovsky (1995), the (new) Deputy Director of the Chernobyl facility, wrote that *two* IAEA safety missions took place in 1994, finding that "Chernobyl operates well compared with other former Soviet nuclear stations". Furthermore, during his opening address at the IAEA meeting on Chernobyl on the 1st April, 1994, Hans Blix (Blix, 1994) stated that:

> the safety review of the mission documented a large number of factors which affect the safety situation at the plant ... The review documented numerous safety shortcomings in the plant's two remaining operational units. Among these shortcomings are some well known problems in the design of the first generation RBMK Unit 1, which have not so far been dealt with.

This statement is further evidence to support the notion that the mission took place, but the lack of publicly available information is, for want of a better term, baffling. No explanation has ever been provided regarding this omission. One would assume that this particular safety mission would be presented as the 'poster child' of the EBP, due to its assessment of the facility responsible for the worse nuclear accident in human history; but nothing can be confidently asserted as no associations can be rendered visible — any explanation regarding the omission would be nothing more than speculation.

Figure 7.2 Human actors of the Smolensk safety mission (source: Lederman 1996, 17)

This is not the place to provide extensive technical details of the recommendations made by the EBP, nor a totalising account of the material augmentations. This section is simply designed to produce an account of an imperatively important node of action created by RBMK no4, one that is a relative unknown to anyone that has not spent years researching the accident. The EBP allows for a returning to the object, the nuclear non-human, and highlights several 'lessons learned' as a consequence of the accident that resulted in a huge number of material augmentations to the Chernobyl facility and its RBMK brethren. The vast majority of these retrofits were to systems deep within the belly of the objects, although some are still clearly visible.

Figure 7.3 Retrofitted control panels within the control room of Unit 1 of the Chernobyl facility. (source: researcher's own photograph 2015)

The EBP graded safety issues in a four category model, ranging from minor to "issues of high safety concern" (EBP 1999, 44). A worrying number of systems fell into the third and fourth category, with the control instrumentation being one of the worst offenders (as was highlighted in Chapter 3). Thus, the EBP recommended that said systems were modernised, which was subsequently carried out extensively throughout the control rooms of every RBMK. Figure 7.3 was taken during the researcher's trip to the Zone, and it delineates the control rod operating system for unit 1. Where the original panel has been cut and the new operating system has been bolted into place can be clearly seen in the image. Granted even the new, augmented system still looks obsolete by modern digital standards, but this image represents a microcosm of the larger and more extensive alterations made to the totality of the nuclear non-human.

These material augmentations to the reactor facility dually account for how the site has evolved over the years, but also highlights another way in which the site has travelled. Until the year 2000, the electrical output from the Chernobyl facility remained, in that, predominantly, RBMK no1 and no2 continued to supply electricity to the Ukrainian national grid. Due to the infrastructural importance of the facility, a delicate process of risk identification, mitigation and material augmentation *had* to be conducted upon the facility. The mere possibility of another incident akin to the explosions of April 1986, manifesting within units 1,2 or 3 was domestically and internationally untenable. In an ideal world, it could be argued that the facility should have been closed immediately (as well as its brethren sites), due to the impossibility of comprehensively increasing its defence-in-depth. Take, for example, the dome-like structures that one associates with a nuclear power station. These spherical domes are designed, amongst other things, to contain a possible explosion within the reactor core – they represent one of the most fundamental material manifestations of the defence-in-depth concept. Now, it may be theoretically possible to install these protective domes in a RBMK facility, but, as no research exploring this augmentation exists, one can assume that the logistical complexities of doing so far outweigh the cost/benefit matrix. Regardless, the small but important incremental improvements to the operating systems of the RBMK fleet (akin to those represented in Figure 7.3) – a direct result of the actions of the EBP – arguably represent the most important changes experienced within the site. Finally, the very need to assess engineering deficiencies of this type of reactor, and the consequential adaptation of the other RBMK facilities, represents an imperatively important travel of the object and the site. Without the agency of RBMK no4 to force the international nuclear community towards a thorough risk mitigation process, the world may have experienced 'The Ingalina/Smolensk/Leningrad/Kursk nuclear power station disaster'.

The fact that there are other RBMKs still being operated today, without major incident since 1986, is testimony to the work and material augmentations of the EBP. In other words, it is no coincidence that an innately unstable series of nuclear non-humans have functioned perfectly since the worst accident imaginable befell one of their mechanical brethren. This is the 'silver lining' of the accident, the actions produced by RBMK no4's agency that resulted in the mitigation of risk, and the consequential improvement of safety of 16 fissioning behemoths spread across eastern Europe and Russia.

7.4 How best to contain the eternal? The mission to settle the site

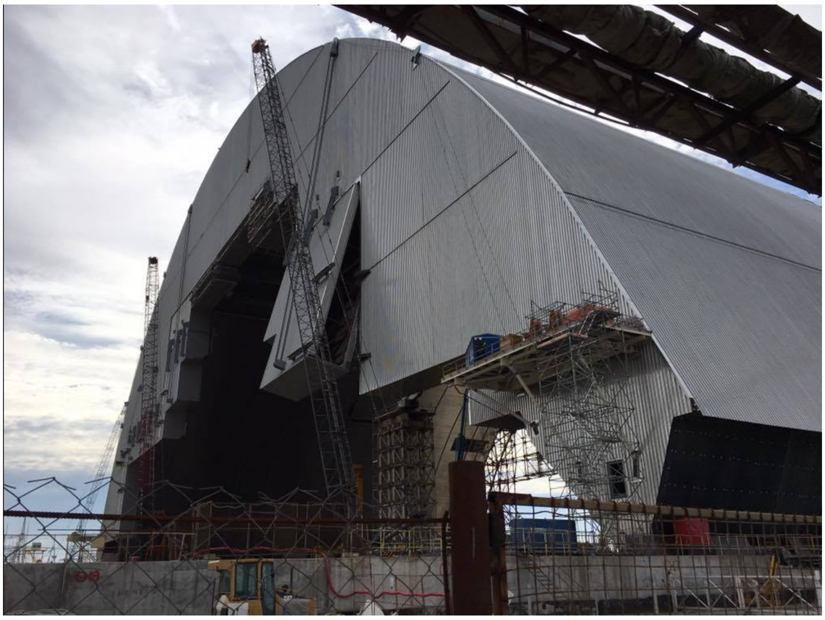

Figure 7.4 The construction site of the new containment structure. (source: researcher's own photograph 2015)

The physical qualities of the hyperobject of radiation can, at times, appear to be taken from the pages of science fiction: an invisible, damaging and invasive entity that will remain dangerous to biological entities for *millennia*. Morton (2013, 58) describes the timescales associated with radioactive materials as "the horrifying, the terrifying and the petrifying", and suggests that these relatively new objects, in effect, project the future into the present. Thus, when dealing with the safekeeping of the byproducts of the fission process, humanity must attempt to cater for thousands years into the future, periods of time that dwarf homo sapiens's residence on our little blue spaceship. This is an ever-present issue, one that is difficult to overcome when dealing with normally functioning nuclear power stations, and even more challenging when thoughts turn to nuclear accidents akin to Chernobyl and the more recent Fukushima incident of 2011. The nuclear industry has developed several methods for 'reprocessing' nuclear waste. Take, for example the UK fleet of Magnox reactors. Their spent fuel is reprocessed at the Sellafield facility, where it is boiled down into its component parts, then the waste elements are fused with molten glass in a bid to seal their material form from any external stimulants, such as water (Buchan 2014). One of the main difficulties associated with the question, 'what comes next?', is centred upon the nexus between computer models, processing what the industry thinks will happen to this fuel/glass mixture over the passing of millennia, and what will actually happen to it: a reality which no living creature today will ever physically witness.

This vignette is a condensed account of the process enacted at a normally functioning nuclear power station, one where the fuel can be extracted from the core in an orderly manner; that is, as the design ethos of the facility allows. Yet, when dealing with a malfunctioning facility, design protocols are rendered useless, and new, emergent, nodes of pragmatic action have to take precedence. RBMK no4's longest standing material manifestation of this reactionary ethos is its iconic original sarcophagus. As covered in Chapter 4, this hastily designed and constructed shelter partially sealed the material form of the nuclear nonhuman from the outside world. It was never designed to be a permeant solution to the issue, merely the improvised method of dealing, for all intents and purposes, with the eternally dangerous materials suffering the reactor hall of unit 4.

Some 30 years have passed since the accident, and it is still not fully mitigated. The hastily constructed sarcophagus was designed to stand for no longer than five years, but it has held its steely resolve for 3 decades; an impressive engineering feat, but one that highlights the worrying bureaucratic impotence experienced when the international community has sought to take action to solve a major problem that really should have been tackled *decades* ago. The troubled political life of the facility since 1986 could provide more than enough material for a full PhD, but this is not the place to detail this particular travel of the nuclear non-human. We have come to the point of physical and metaphorical final entombment: the physical covering of RBMK no4, and the last travel of the agency of the nuclear non-human.

Due to the structural inadequacies of the original sarcophagus, it has been known for decades that it did not represent a permanent solution of entombment. The main issue is that, over the years, the rigidity of the structure has weakened significantly. Thus, in 2003, the stabilisation project was initiated, and three years later the strengthening of the shelter, and the surrounding building was completed (Kovan 2006). This process was, in effect, tasked with preparing the rickety building for its final resting state, and it should be viewed as the first stage of the new containment project.

The new containment structure was designed by a consortium of Bethel and Battelle of the United States, Electricite de France, and the KCK Consortium (Lyubchenko *et al* 2003). It stands 257 metres wide, 150 metres deep and 108 metres high, and when it is finished it will be rolled over the entire building that houses RBMK no4. It is, hence, the largest moving object on Earth (Kovan 2006) and it is designed to sealing the highly radioactive materials that cannot be removed from the shattered reactor for the next 100 years. Figure 7.4 was taken during the researcher's trip to the Zone, and it delineates the western face of the structure. The sheer scale of the object is difficult to fathom. It sprawls in every direction and it has come to dominate a landscape that has remained relatively unchanged for 30 years. When it is finished and finally moved into place, this event will represent the returning of the site of Chernobyl to an atonic state – peaceful and stable engendered by a new transcendental object. The iconic skyline of the reactor facility will forever be hidden (the original chimney has already been removed) under this mass of steel and aluminium, and RBMK no4 will likely never see the light of day again. In other words, this massive nonhuman will finally put the genie back in the bottle and, hopefully, the Chernobyl accident will be assigned to the annals of human history.

In theory, this is the planned trajectory for the site, but nuclear accidents have a worrying ability to ignore our best mitigating efforts. This week, for example, has seen radiation levels spike to perviously unseen heights within the Fukushima facility – years after the tsunami. The discourses surrounding the new containment structure of Chernobyl are definitive, and allude to the conclusion of the accident. There is no reason to disbelieve these sentiments. The original sarcophagus, a hastily designed structure, and one constructed in truly abhorrent conditions, has been an exemplary shelter. The only real issue that has befallen RBMK no4 in the past 10 years occurred when a section of the sarcophagus's roof collapsed; but, as the structure was only designed to stand for 5 years, one incident of this nature in 30 years speaks to a favourable risk/reward ratio. It must always be remembered that the original shelter is a product of 1980s design and a truly unique set of circumstances. The new containment project has featured none of the panic of 1986 and has benefited from international finance/design collaboration.

For all that, there can be no ignoring the potential destructive/disruptive abilities of malfunctioned nuclear nonhuman, nor the hyperobject radiation, and as a result RBMK no4 will require constant supervision throughout the years. The new containment project has been designed, at great expense, to assign RBMK no4 once more to 'the background' – a stable and protected final place of residence. Thus, at least for the time being, it appears that RBMK no4 has been settled under its new shelter, and international nuclear attention should be directed upon the far more pressing matter of the Fukushima incident. This research has revisited the first major nuclear accident that the world has ever seen, and there is no escaping the historical nature of the study. Fukushima is *the* current problem, one that has raged for years longer than RBMK no4. For all intents and purposes, now, in light of the achievements of the EBP and the new containment project, we should view 'the Chernobyl accident' as settled, finished, mitigated, and begin to help with the ever expanding check list of issues created by the nuclear nonhumans, BWR no1, 2 and 3, of the Fukushima Daiichi nuclear power station.

7.5 A moment of conceptual consideration

A concluding passage would not be complete without a moment of critical reflection upon one's methods and conceptual framework: a valuable process, and one which can lead to more nuanced future deployments. Latourian methods, philosophy and sensibilities form the backbone of this analytical endeavour. From his meticulous foundational work, which focused upon the difficulties of the modernism project, to his most recent book that finesses his version of ANT, Latour's overall project has allowed this research to conceptualise an object at the centre of the analysis, and provided a means of accounting for the scientific works tasked with actively 'doing' nuclear practice. Fundamentally, I believe that the choice of theorist and method has been a success, as it is through Latour's intellectual project that this account has been produced, but I am not blind to the other ANT variables that may have coloured my interpretation of the accident.

Latour's ANT is very much concerned with the 'nuts and bolts' of a network, the 'normal' workings of a situation and how these machinations play out to assemble the interconnected constellations of humans and nonhumans. This characteristic of the approach has served the empirical chapters well, due to the methodical nature of scientific and engineering practices. As has been highlighted throughout the empirical core of this research, the discourses of these areas of enquiry speak in purposefully efficient language, and, from the outside, seem to be enacted in an orderly manner. Thus, Latour's ANT is suited to the following of scientific actors within their network, no doubt a byproduct of his own interest with 'the sciences'. Furthermore, it would appear that the style of 'reassembling' present within this account has been, perhaps, influenced by the ordered nature of these works; in that the narrative follows a similar chronological trajectory to the style within the discourses of nuclear engineering/physics. Personally, I prefer an ordered account, one that allows the actions of the actors to take centre stage, as apposed to a more creatively divergent take on the material. Personal preferences aside, I am not blind to the different styles of account that could have been produced with this material, but I feel that when dealing with a phenomena as important as a level 7 nuclear accident, for want of a better terms, one should shy away form experimental discursive tactics and instead ground the empirical work within a structured narrative.

The main point of friction within the research's conceptual structure is found when conceptualising the event of the explosion. As covered above, Latour's version of ANT has diligently allowed the empirical chapters to reassemble the intricate actions of the post-accident epoch, but the 'explosive newness' of the event is under-theorised. The augmentation of Latour's ANT with Shaw's evental geography was tasked with equipping the methodology with a means of identifying the event, a violent explosion that fundamentally altered a host of different 'worlds' in the process. While I do believe that this merging was a partial success, other, maybe more streamlined, tactics could have been deployed, arguably, to achieve a full account of the phenomena. ANT is more than just Latour, and I have to admit that I suffered from tunnel vision when choosing which version to deploy. The works of Law (2004) or Callon (1986, 1999), two of the central figures of the ANT project, could have been utilised as a means of conceptualising the event 'in house', as opposed to attempting a merger with a foreign body of work. Regardless, the merging of Latour's ANT with Shaw's evental geography should be viewed as one of the successes of this research. It represents a chance taken, one which sought to improve Latour's mythological project, and to award Shaw's theoretical structure with a methodological backbone. In other words, I use the strongest assets of these two conceptual constructs to tackle their respective weak spots.

One of the most frustrating aspects of the entire project has been its unavoidable historical nature. Due to the viscosity of the hyperobject of radiation, the Chernobyl accident can appear to be an ever present issue, in that, due to the lengths of time associated with radioactive decay, — coupled with the issues experienced by international community when trying to settle RBMK no4 — the accident has *appeared* to be an ever present issue for some 30 years. This duration is true in some cases, but I found that the vast majority of people professionally connected to the mitigation of the accident have either retired or been left unidentified within the discourses. Due to the severity of the situation, it appears that only experienced scientists, engineers and medical professionals were drafted into the network. Such actors at the pinnacle of their respective fields tend now to have one thing in common, an advancing age. Thus, a 50 year old professor in 1986 is now 80 and long since retired.

This historical dimension presented a methodological issue, especially when considering the adopted approach's mantra of 'follow the actors'. Yes, it is relatively easy to do so within documents, journal articles and, international reports, but I wanted to speak to more people during this process. The 'travelling archive' that was identified, and duly navigated through, does answer my central research question, but I would have preferred to supplement this analysis with several in-depth interviews with human actors involved within RBMK no4's risky network. Regardless, I believe that the backbone of this research's conceptual and methodological architecture represents a means of analysing 'current' industrial accidents. The extensive discursive exploration – that is, the charting of the actor of RBMK no4 through the pages of documents – could be repeated within another context, and the use of Latour's ANT equips the analysis with the ability to introduce sustained engagements with both human and non-human actors. This meta-charting is the biggest success of the research, representing a blueprint to explore other nuclear non-human related incidents: situations where a nuclear nonhuman has massively malfunctioned and, in the process, forcefully directed huge sways of human action, all tasked with understanding, rectifying and, ultimately, settling a fissioning or otherwise disintegrating object.

7.6 The final concluding remark

A lot has happened since the explosion of 1986. Entirely new worlds of risk were created, assessed, developed upon, and mitigated. Heterogenous nodes of action have been engendered throughout a host of domains of reality, and vast swathes of environmental radioactive material have decayed. This research has taken seriously the materiality of the accident, and embraced the sciences of the disciplines tasked with actively mitigating the accident and the risks that it created. It has detailed arguably the worst nuclear accident that has ever befallen our little blue spaceship, but it has done so pragmatically. At no point has this research tried to claim that Chernobyl was anything other than a horrendous phenomena, but it has sought to engender an actor-led contextualisation that presents a representation of its *real* dangers/impacts devoid of geopolitical/environmentalist mediations.

This researcher, I myself, believes in nuclear energy. Humanity stands on the brink of irreversibly altering the thin layers of gas that protect us from the borderline inconceivable harshness of space. Carbon emissions are a bigger threat to our shared residence on this ball of dirt than the AIDS epidemic, terrorism and another round of economic self destruction brought about by the villainous combination of neoliberalism and innate human greed. There is no singular means of combating these issues, for they require a systematic process of self-assessment and pragmatically educated actions. The United States Environmental Protection Agency (2015) estimates that 65% of the world's total carbon dioxide emissions are a product of fossil fuels and industrial processes, with 25% of that figure a product of energy production. Fossil fuel power stations are inefficient, polluting and based upon an archaic technology – we possess the technology, within the current iteration of nuclear fission and renewable methods, to phase out 'traditional' means of producing electricity. This move alone would put a significant dent in global carbon emissions.

This research has focused upon the absolute worst in class: a poorly designed, dangerously operated and, essentially, unlucky nuclear reactor. It has also highlighted the ways in which the nuclear industry has learned from the accident, improved safety precautions and moved into a new era of intense risk mitigation. The entire industry is now significantly safer due to RBMK no4. Taking this fact into consideration, can we, as a species, move away from a technology that could meet our every growing energy needs for the next 2000 years, one that produces no carbon in the process of producing electricity? Granted the issue of the waste is an ever-present issue, a hyperobject that will ontologically outlive anyone living today, but as big a problem as the eroding of our planet's atmospheric protection? We can store nuclear waste deep underground, and in the future we might even develop a means of closing the fuel cycle, but, as things stand just now, we have no way of repairing the damage caused by unchecked carbon emissions. Pragmatism in the face of an entire civilisation's worth of agencies is required.

A doctoral research project is a sustained practice of 'researching' a chosen phenomena and also, crucially, a personal training exercise. This thesis project has forced me to consume huge amounts of technical information, from disciplines distant from my own academic training. This process of self-tuition has resulted in a thesis that provides detailed accounts of several technical and engineering aspects of nuclear technology, environmental radiation and the physical composition of the atmosphere. It has been achieved through a relentless belief in, and commitment to, ANT and its methodological apparatus. The final product, outwith this thesis, is a human geographer attuned to and ready for interdisciplinary research. As covered in section 7.1, this research could have focused upon a host of other travels of RBMK no4, but an altogether more serious scientific direction was chosen as it was believed that this type of enquiry would force the researcher to become accustomed with the disciplines that actively 'do' nuclear related activities. Nuclear related issues are multifaceted and complex, therefore requiring the skill sets of a diverse pool of academics if they are to be comprehensively tackled. An ANT social scientist's role within such a team is obviously orientated around accounting for the 'social' dimensions of the situation, but this role would be compromised if he or she could not articulately converse with the scientific members of the team. An educated understanding of the science behind radiation, the engineering of nuclear reactors and the practices of each domain are essential components of a social scientist's skillset that seeks to operate within such an interdisciplinary setting.

This research project represents this researcher's journey to this point, and in the process it has reassembled the imperatively important travels of RBMK no4. From positive reactivity coefficients, atmospheric processes and the ontology of radiation, this thesis provides a window into a learning process, one that has produced an interdisciplinary-ready human geographer.

References:

Abramov, V.I., Fedorenko, O.M. and Shevchenko, V.A., (1992). Genetic consequences of radioactive contamination for populations of Arabidopsis. Science of the total environment, 112(1), pp.19-28.

Adam B (2000) The Risk Society and Beyond. SAGE: London

Adams J (1995) Risk. UCL Press, London.

Aden, V.G., Bibliashvili, Y.K., Zaimovskii, A.S., Kalishnikov, V.V., Nikolaev, V.A., Nikulina, A.V., Solyanyi, V.I., Filippov, V.N., Yamnikov, V.S., Goncharov, V.V. and Dubrovin, K.P., (1977) Fuel elements of the RBMK-1000 reactor. Atomic Energy, 43(4), pp.865-870.

Afanas'ev, A.M., Babajtsev, M.N., Krayushkin, A.V., & Kubarev, A.V. (1991). On the maximum xenon poisoning after RBMK reactor shutdown. Atomnaya Ehnergiya, 71(3), 265-266.

Afanasieva, A.A., Burlakov, E.V., Krayushkin, A.V. and Kubarev, A.V., (1993) The characteristics of the RBMK core. Nuclear technology, 103(1), pp.1-9.

Ahearne JF (1987) Nuclear Power after Chernobyl. Science 8, vol 236, no 4802, 673 - 679.

Alexander P (1965) Atomic radiation and life. Penguin Books, Middlesex

American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders (DSM-5®). American Psychiatric Pub.

Ancius, D., Ridikas, D., Remeikis, V., Plukis, A., Plukiene, R. and Cometto, M., 2005. Evaluation of the activity of irradiated graphite in the Ignalina Nuclear Power Plant RBMK-1500 reactor. Nukleonika, 50(3), pp.113-120.

Andersen H (1997) Categorisation, Anomalies and the Discovery of Nuclear Fission. Stud. Hist. Phil. Mod. Phys, vol 27, no4. 463-492

Anspaugh, L. R., Catlin, R. J., & Goldman, M. (1988). The global impact of the Chernobyl reactor accident. Science, 242(4885), 1513-1519.

Apostolakis G.E (2004) How Useful Is Quantitative Risk Assessment? Risk Analysis, Vol 24, no3

Averbeck, D. (2009). Does scientific evidence support a change from the LNT model for low-dose radiation risk extrapolation?. Health physics, 97(5), 493-504.

Backe S, Bjerke H, Rudjord A L and Ugletveit F (1986) Deposition of caesium in Norway after the Chernobyl accident National Institute of Radiation Hygiene, report no 6.

Bain B (2006) Blood cells: a practical guide. Blackwell, Oxford.

Banks, M., Lovatt, A., O'Connor, J., & Raffo, C. (2000). Risk and trust in the cultural industries. Geoforum, 31(4), 453-464.

Barry R & Chorley R (2009) Atmosphere, weather and climate. Routldege Ltd, London.

Beck, Harold L, Bennett & Burton G (2002) Historical Overview of atmospheric nuclear weapon testing and estimates of fallout in the continental united states. Health Physics, Vol 82, issue 5, 591-608

Beck, U. (1987). The anthropological shock: Chernobyl and the contours of the risk society. Berkeley Journal of Sociology, 153-165.

Beck U (1992) Risk Society: Towards a New Modernity. SAGE: London

Beck, U. (1992a). From industrial society to the risk society: questions of survival, social structure and ecological enlightenment.

Beck U (1995) Ecological Politics in an Age of Risk. Cambridge: Polity Press.

Beck, U. (1997). Global risk politics. The Political Quarterly, 68(B), 18-33.

Beck U (1998) Democracy Without Enemies. Cambridge: Politics Press

Beck U (1999) World Risk Society. Cambridge: Polity Press.

Beck, U. (2000). Risk society revisited: theory, politics and research programmes. The risk society and beyond: Critical issues for social theory, 211-229.

Beck, U. (2002). The silence of words and political dynamics in the world risk society. Logos, 1(4), 1-18.

Beck, U., Bonss, W., & Lau, C. (2003). The theory of reflexive modernization problematic, hypotheses and research programme. Theory, culture & society, 20(2), 1-33.

Belloni J (2011) Historic landmarks in radiation chemistry since early observations by Marie Sklodowska-Curie and Pierre Curie. Nucleonic, Vol 56, issue 3, 203-211

Belyakov, Oleg V., Friedrich Steinhäusler, and Klaus-Rüdiger Trott. (2000) Chernobyl liquidators. The people and the doses. Proceedings of the Tenth International Congress of the International Radiation Protection Association, Hiroshima, Japan, 14–19 May 2000..

Belyaev, S. T.(1993) The Chernobyl-4 entombment. Yesterday, today, tomorrow.

Belyaev S, Velikhov E, Kagan M, Kadomtsev B, Ponomarev-Stepnoi N, and Chernoplekov A (1993) Anatoli Petrovich Aleksandrov (on his ninetieth birthday). Usp, Fiz, Nauk 163, 99 - 102

Benneworth, P. and Hospers, G.J., (2007). The New Economic Geography of Old Industrial Regions: Universities as Global–Local Pipelines. Environment and Planning C: Government and Policy, 25(6), pp.779-802.

Bentley, C.B., Robison, J.H. and Spengler, R.W., (1983). Geohydrologic data for test well USW H-5, Yucca Mountain area, Nye County, Nevada (No. USGS-OFR–83-853). Geological Survey, Denver, CO (United States).

Berkemeier, M., Bowen, W.Q., Hobbs, C. and Moran, M., (2014). Governing uranium in the United Kingdom. DIIS Reports, Danish Institute for International Studies.

Berthold A, Bogorinski P, Bykov V, Redko V, Erickson L, Kadkin ye, Kondratiev S, Simonov I, Smyshliaieva S, Yu Yesipenko (2002) Application of Safety Standards and rules in the shelter implementation plan at the destroyed power unit of Chernobyl NPP. Nuclear Energy for New Europe. International Conference.

Bergstrom, C., (2007). Measuring the value and prestige of scholarly journals. College & Research Libraries News, 68(5), pp.314-316.

Berndt C and Boeckler M (2009) Geographies of circula- tion and exchange: Constructions of markets. Progress in Human Geography 33: 535–551.

Berndt C and Boeckler M (2011) Geographies of markets: Materials, morals and monsters in motion. Progress in Human Geography 35: 559–567.

Bertin E (1978) Introduction to X-ray Spectrometry Analysis. Plenum Press, New York and London

Bingham, N., (2003). Writing reflexively. Using social theory: Thinking through research, pp. 89-104.

Bingham, N., (2006). Bees, butterflies, and bacteria: biotechnology and the politics of nonhuman friendship. Environment and Planning A, 38(3), pp.483-498.

Bingham, N., (2008). Slowing things down: Lessons from the GM controversy. Geoforum, 39(1), pp.111-122.

Bingham, N., Hinchliffe, S., Lakoff, A. and Collier, S.J., (2008) Mapping the multiplicities of biosecurity. Biosecurity interventions: global health and security in question, pp.173-193.

Bingham, N. and Thrift, N., (2000). The geography of Bruno Latour and Michel Serres. Thinking space, 9, p.281.

Blix H (1994) Director General's Opening Remarks at Meeting on Chernobyl. Accessed at https://www.iaea.org/newscenter/statements/director-generals-opening-remarks-meeting-chernobyl-0

Bogost, I., (2010) Process vs. Procedure. In Fourth International Conference of the Whitehead Research Project.

Bogost I (2012) Alien Phenomenology, or What It's Like to Be a Thing. Minneapolis: Minnesota University Press.

Bourbeau, P., (2013). Resiliencism: Premises and promises in securitisation research. Resilience, 1(1), pp.3-17.

Bouville, A. (1995) The Chernobyl Accident. Radiation Protection Dosimetry 60.4: 287-293.

Braun, B., (2004) Querying posthumanisms. Geoforum, 35(3), pp.269-273.

Brenner, D.J., Doll, R., Goodhead, D.T., Hall, E.J., Land, C.E., Little, J.B., Lubin, J.H., Preston, D.L., Preston, R.J., Puskin, J.S. and Ron, E., (2003). Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. Proceedings of the National Academy of Sciences, 100(24), pp.13761-13766.

Brice, J., (2014) Attending to grape vines: perceptual practices, planty agencies and multiple temporalities in Australian viticulture. Social & Cultural Geography, 15(8), pp.942-965.

Bromley S (2000) Political Ideologies and the Environment. in Goldblatt D (ed) Knowledge and the Social Sciences: Theory, Method and Practice. London: Routlegde.

Brown, R.L. and Kaplow, J.M., (2014) Talking peace, making weapons IAEA technical cooperation and nuclear proliferation. Journal of Conflict Resolution

Bryant, L.R (2011) The democracy of objects. Open Humanities Press.

Brynildsen, L.I., Selnaes, T.D., Strand, P. and Hove, K., (1996). Countermeasures for Radiocesium in Animal Products in Norway after the Chernobyl Accident-Techniques, Effectiveness, and Costs. *Health Physics*, *70*(5), pp.665-672.

Burykina L (1962) Changes in the peripheral blood following a high-dose administration of radioactive ruthenium, strontium and caesium. In Letavet A & Kurlyandskaya E (eds) The Toxicology of Radioactive substances, Vol 1. Pergamon Press, London.

Calabrese, E.J., 2004. Hormesis: a revolution in toxicology, risk assessment and medicine. EMBO reports, 5(1S), pp.S37-S40.

Calabrese, E.J. (1989). A single exposure to a carcinogen can cause cancer. Documentation, limitations and implication for risk assessment. Proc. Chem. Defense Research Conference, pp. 19-615.

Calabrese, E.J. and Baldwin, L.A., (1998). Hormesis as a biological hypothesis. Environmental Health Perspectives, 106(Suppl 1), p.357.

Calabrese, E. J (2009) The Road to Linearity: why linearity at low doses became the basis for carciongen risk assessment. Arch Toxicol, 83: 203 - 225.

Calabrese, E.J., and Ricci, P.F. (2011). How hormesis will change the risk assessment process. In: Nriagu JO (Editor) Encyclopedia of Environmental Health, Volume 3, pp. 95-99. Burlington:Elsevier.

Calabrese, E. J (2011) Toxicology rewrites its history and rethinks its future: giving equal focus to both harmful and beneficial effects. Environ Toxicol Chem 30(12):2658–2673

Calabrese, E.J. (2012a). The hormetic dose response. Mutagenesis, 27(6):795-795.

Calabrese, E.J. (2012b). Hormesis: Improving predictions in the low-dose zone. Experientia Supplementum 101:551-564.

Calabrese, E. J. (2013). Origin of the linearity no threshold (LNT) dose–response concept. Archives of toxicology, 87(9), 1621-1633.

Calabrese, E.J. (2013b). Hormesis. In: Encyclopedia of Enviornmetrics, Second Edition (A.-H. El-Shaarawl and W. Piegorsch, Editors). John Wiley & Sons Ltd: Chichester, UK. DOI: 10.1002/9780470057339.vah014.pub2. Published online 1/15/2013.

Calabrese, E.J. (2013c). Hormesis: Toxicological foundations and role in aging research. Exper. Gerontol. 48:99-102.

Calabrese, E.J., Iavicoli, I., and Calabrese, V. (2013). Hormesis: Its impact on medicine and health. Hum. Exper. Toxicol., 32(2):120-152.

Camino, E. and Colucci-Gray, L., 2015. The nuclear power option: exploring boundaries and limits, asking open questions. Visions for Sustainability, 4, pp.22-42.

Canadian Nuclear Safety Commission (CNSC), (2009), Low-Level Radiation: How the Linear No- Threshold Model Keeps Canadians Safe. Available at: http://www.nuclearsafety.gc.ca/eng/mediacentre/perspectives/linear_no_threshold_model.cfm

Carnino A & Gasparini M (2002) Defence-in-depth and development of safety requirements for advanced nuclear reactors. In Nuclear Energy Agency (NEA) (2002) Advanced Nuclear Reactor Safety Issues and Research Needs: Workshop Proceedings. Paris, France, 18-20 February. Nuclear Safety, OECD Publishings. Paris

Castree, N. and Nash, C., (2006) Posthuman geographies.

Castel, B, (1991) 'From Dangerousness to Risk', in Burchell, G, Gordon, C and Miller, P (eds), The Foucault Effect. Studies in Governmentality, London: Harvester/Wheatsheaf, pp 281-298

C.D. Jackson Papers (1953.a) Box 30, Atoms for Peace

C.D. Jackson Papers (1953.b) Box 100, Speech Texts

Cepin M & Mavko B (1996) Probabilistic safety assessment improves surveillance requirements in technical specifications. Reliability Engineering and System Safety 56, 69-77

Chan, P.S.W. and Dastur, A.R., (1989) The physical basis for the void reactivity effect and its dependence on absorber rod configuration in the RBMK-1000. Nuclear Science and Engineering, 103(3), pp.283-288.

Charles, M. (2001). UNSCEAR Report 2000: sources and effects of ionizing radiation. Journal of Radiological Protection, 21(1), 83.

Charleson, A. W., & Taylor, M. (2000). Towards an earthquake architecture. In Proceedings of the 12th World Conference on Earthquake Engineering, New Zealand National Society for Earthquake Engineering, Paper (Vol. 858).

Chapura M (2009) Scale, causality, complexity and emergence: rethinking scale's ontological significance. Transactions of British Geographers 34 462 - 474

Chernousenko VM (1991) Chernobyl: Insight from the Inside. Springer Berlin.

Cidell J (2012) Just passing through: the risky mobilities of hazardous materials transport. Social Geography, vol 7, 13-22.

Clarke R.H & Valentin J (2008) The History of ICRP and the evolution of its Policies. ICRP Publication 109

Cloke, P. and Pawson, E., (2008) Memorial trees and treescape memories. Environment and Planning D: Society and Space, 26(1), pp.107-122.

Cohen, B. L. (2005). Test of the linear-no threshold theory: rationale for procedures. Nonlinearity in Biology, Toxicology, Medicine, 3(3), dose-response.

Cohen, B. L. (2012). The cancer risk from low level radiation. In Radiation Dose from Multidetector CT (pp. 61-79). Springer Berlin Heidelberg.

Cole, J.C., Sawyer, D.A. and Trudeau, D.A., 1996. Summary of hydrogeologic controls on ground-water flow at the Nevada Test Site, Nye County, Nevada. US Department of the Interior, US Geological Survey.

Collinge C (2006) Flat ontology and the deconstruction of scale: a response to Marston, Jones and Woodward. Transactions of British Geographers, 31 244-251

Comber, A., Fisher, P. and Wadsworth, R., (2003) Actor–network theory: a suitable framework to understand how land cover mapping projects develop?. Land Use Policy, 20(4), pp.299-309.
Considine, Glenn, ed. (2002). Van Nostrand's Scientific Encyclopedia (9th ed.). New York: Wiley Interscience.

Cotton W, Bryan G & van den Heever S (eds) (2011) Storm and Cloud Dynamics. International Geophysics. Vol 99, 1-809.

Cox, K (1998) Spaces of dependence, spaces of engagement and the politics of scale, or: looking for local politics. Political Geography 17, 1-23

Cresswell A.J, Sanderson D.C.W & White D.C (2006) 137C measurements uncertainties and detection limits for airborne gamma spectrometry (AGS) data analysed using a spectral windows method. Applied Radiation and Isotopes, 64 (2), 247-253

D'Auria, F., Gabaraev, B., Radkevitch, V., Moskalev, A., Uspuras, E., Kaliatka, A., Parisi, C., Cherubini, M. and Pierro, F., (2008). Thermal-hydraulic performance of primary system of RBMK in case of accidents. Nuclear Engineering and Design, 238(4), pp.904-924.

Daglish, J. (1988). Radiophobia and radiation protection.

Dalton J (1808) A New System of Chemical Philosophy; part 1. S. Russell: London

Dalziel, S. P. C. (1988.) Chernobyl: recovery operations and the entombment of Reactor 4. International seminar on the decommissioning of nuclear facilities, 6th/7th July 1988, London Hilton on Park Lane.

Daniels, R.V (2007) Soviet Federalism and the Breakup of the USSR, In Daniels R.V: The rise and fall of Communism in Russia. Yale University Press, London.

Dean M (1999) Risk, Calculable and Incalculable. In Lupton D (ed) 'Risk and Sociocultural theory: New Directions and Perspectives. Cambridge: Cambridge University Press: 131-59

Defert, D, (1991) 'Popular Life and Insurance Technology', in Burchell, G, Gordon, C and Miller, P (eds), Foucault Effect, Studies in Governmentality, London: Harvester Press, pp 211-34

Deleuze G (1994) Difference and Repetition. Continuum, London

Dendy, P. P., & Brugmans, M. J. P. (2014). Low dose radiation risks. The British journal of radiology.

The Dispatch (1996) Firefighters recall Chernobyl big Blaze. Tuesday April 16th. [Accessible at http://news.google.com/newspapers?nid=1734&dat=19960416&id=kCshAAAAIBAJ&sjid=BVMEAAAAIBAJ&pg=6691,3843417]

Donovan, A. and Oppenheimer, C., 2014. Managing the uncertain earth: geophysical hazards in the risk society. The Geographical Journal, 180(1), pp.89-95.

Doss, M. (2013). Linear no-threshold model vs. radiation hormesis. Dose-Response, 11(4), dose-response.

Douglas M (1985) Rick Accessibility According to the Social Sciences. SAGE: New York

Douglas M (1992) Risk and Blame: Essays in Cultural Theory: Routlege: London.

Drottz-Sjoberg, B. M., & Persson, L. (1993). Public Reaction to Radiation: Fear, Anxiety, Or Phobia?. Health Physics, 64(3), 223-231.

Dubrova, Y.E., Nesterov, V.N., Krouchinsky, N.G., Ostapenko, V.A., Neumann, R., Neil, D.L. and Jeffreys, A.J., (1996). Human minisatellite mutation rate after the Chernobyl accident. Nature, 683-686

Dunlop, J.B., (1993) The rise of Russia and the fall of the Soviet empire (p. 5475). Princeton: Princeton University Press.

Ellegren, H., Lindgren, G., Primmer, C.R. and Møller, A.P., (1997). Fitness loss and germline mutations in barn swallows breeding in Chernobyl. Nature, 389(6651), pp.593-596.

Elliott, A. (2002). Beck's sociology of risk: a critical assessment. Sociology, 36(2), 293-315.

Emel'yanov, I.Y., Postnikov, V.V. and Volod'ko, Y.I., 1980. Power distribution monitoring and control for a RBMK reactor. Atomic Energy, 48(6), pp.360-365.

Erlandsson B & Isaksson M (1988) Relation between the air activity and deposition of Chernobyl debris. Environment International, Vol 14, 165-175

Escobar A (2006) The 'ontological turn' in social theory. A commentary on 'Human geography without scale', by Sallie Marston, John Paul Jones II and Keith Woodward. Transactions of the Institute of British Geographers. 32 106 - 111

European Commission (1998) De Cort M, Dubois G, Fridman Sh, Germenchuk M, Izrael Yu, Janssens A, Jones A R, Kelly G N, Kvasnikova E V, Matveenko I I, Nazarov I M, Pokumeiko Yu M, Sitak V A, Stukin E D, Tabachny L Ya, Tsaturov Yu S, & Avdyushin S I. Atlas of Caesium Deposition on Europe After The Chernobyl Accident. Office for Offical Publications of the European Communities, Brussels.

Ewald, F, (1991) 'Insurance and Risk', in Burchell, G, Gordon, C and Miller, P (eds), The Foucault Effect. Studies in Governmentality, London: Harvester/Wheatsheaf, pp 197-210

Extra Budgetary Programme of the IAEA (EBP) (1999) Final report of the programme on the safety of WWER and RBMK nuclear power plants. Special Projects Unit: Nuclear Installation Safety Division of the International Atomic Energy Agency. IAEA-EBP-WWER-RBMK-15

Evstratov, F.F., Kolossov, A.A., Kuzmin, A.A., Shustov, E.I., Yakunin, V.A., Abramovich, Y.I. and Alebastrov, V.A., (1994). Over-the-horizon radio location in Russia and Ukraine (the history and achievements). Onde Electr, 74(3), pp.29-33.

Falconer I (1987) Corpuscles, Electrons and Cathode Rays: J.J Thomson and the 'Discovery of the Electron'. Table of Contents, vol 20, issue 3,

Farhi, E., Ferran, G., Haeck, W., Pellegrini, E. and Calzavara, Y., (2015). Light and heavy water dynamic structure factor for neutron transport codes. Journal of Nuclear Science and Technology, 52(6), pp.844-856.

Farias, I. and Bender, T. eds., (2012). Urban assemblages: How actor-network theory changes urban studies. Routledge.

Fedosov, A.M. (1993). The influence of burnable poisons on the void reactivity in RBMK. Atomnaya Ehnergiya, 75(1), 67-69.

Feinendegen, L. E. (2005) 33 Evidence for beneficial low level radiation effects and radiation hormesis.

Feinendegen, L. E. (2014). Evidence for beneficial low level radiation effects and radiation hormesis. The British journal of radiology.

Fischer D (1997) History of the International Atomic Energy Agency: the first forty years. VIC Library Cataloguing in Publications.

Foucault M (1975) Discipline & Punish: The Birth of the Prison. Peregrine Books

Foucault M (1977) Nietzsche, Genealogy, History. In Language, Counter-memory, Practice: Selected Essays and Interviews, edited by D.F Bouchard. Ithaca: Cornell University Press

Foucault M (1981) The order of discourse. In Young, R (ed) Untying the text: a post-structural anthology. Boston, MA Routledge, 48 - 78

Foucault M (1989) Archaeology of Knowledge. Routledge, London.

Foucault M (1994) Society Must Be Defended, in Michel Foucault, Power essential works of Foucault 1954 - 1984. Penguin Books,

Foucault M (1994) Governmentality in Michel Foucault, Power essential works of Foucault 1954 - 1984. Penguin Books,

Foucault M (1994) Questions of method. in Michel Foucault, Power essential works of Foucault 1954 - 1984. Penguin Books

Frischknecht R, Heijungs R & Hofstetter P (1998) Einstein's Lesson for Energy Accounting in LCA. Einstein's Lessons, in LCA Methodology.

Gale RP (1988) Chernobyl: The Final Warning. Warner Books Inc. New York

Garrett, B.L (2010) Urban explorers: Quests for myth, mystery and meaning. Geography Compass, 4(10), pp.1448-1461.

Geras' kin, S.A., Fesenko, S.V. and Alexakhin, R.M., (2008). Effects of non-human species irradiation after the Chernobyl NPP accident. Environment International, 34(6), pp.880-897.

Gerber, L. G. (1982). The Baruch Plan and the Origins of the Cold War. Diplomatic History, 6(1), 69-96.

Ghose, R. and Pettygrove, M (2014) Actors and networks in urban community garden development. Geoforum, 53, pp.93-103.

Giddens A (1998) Risk Society: The context of British Politics. in Franklin J (ed) The Politics of Risk Society. Polity Press: Cambridge.

Gilbert E, Tarone R & Ron E (1998) Thyroid Cancer Rates and I131 Doses from Nevada Atmospheric Nuclear Bomb Tests. National Cancer Institute, Vol 90, issue 21, 1654-1660

Gilbert, E. S. (2009). Ionising radiation and cancer risks: what have we learned from epidemiology?. International journal of radiation biology, 85(6), 467-482.

Gilmore G (2008) Practical Gamma-Ray Spectrometry. Wiley & Sons Ltd, West Sussex.

Girard, P., & Dubreuil, G. H. (1996). Stress in accident and post-accident management at Chernobyl. Journal of Radiological Protection, 16(3), 167.

Glasstone, S. and Sesonske, A., (2012) Nuclear reactor engineering: reactor systems engineering. Springer Science & Business Media.

Glocker R (1932) The concept of dosage and the definition of the r-Unit (Roentgen Unit) Available at http://pubs.rsna.org/doi/pdf/10.1148/18.1.93 [Accessed 4/914]

Golikov, V.Yu., Balonov, M.I., & Ponomarev, A.V. Balonov, M.I. (Ed.). (1993). Estimation of external gamma radiation doses to the population after the Chernobyl accident. United States: Research Enterprises.

Goraczko, W., & Latek, S. (1999). Radiation education versus' radio-phobia'-public perception of radiation.

Gorbachev BI (2002) The causes and scenario of the Chernobyl accident, and radioactive release on the CHNPP Unit-4 site. Genshiryoku Anzen Kenkyu Group (Nuclear Safety Research Group, Japan). Available at http:// www.rri.kyoto-u.ac.jp/NSRG/reports/kr79/KURRI-KR-79.htm [10 April 2014]

Gottfried, K.L.D. and Penn, G. eds., (1996). Radiation in medicine: a need for regulatory reform. National Academies Press.

Gould, P (1990). Fire In the Rain: The Dramatic Consequences of Chernobyl. Baltimore, MD: Johns Hopkins Press.

Graziani G & Zarimpas N (1988) Meterological data related to the Chernobyl accident. EUR report 11890, Office of Official Publications, Luxembourg.

Hall E.J & Brenner D.J (2008) Cancer risks from diagnosticc radiology. Dr J Radiol vol 81. 362 - 378

Hamblin, J.D., Carlisle, R.P. and Zenzen, J.M., (1998). Supplying the Nuclear Arsenal: American Production Reactors, 1942-1992

Hamman H & Parrott S (1987) Mayday at Chernobyl: One Year On, The Facts Revealed. New English Library Paperbacks. London

Harman, G., (2011) The quadruple object.

Harman, G., (2010) Object-oriented philosophy. Towards Speculative Realism: Essays and Lectures, pp.93-104

Hawkes N, Lean G, Leigh D, McKie R, Pringle P, Wilson A (1986) The Worst Accident in the World. Chernobyl: The End of the Nuclear Dream. William Heinemann, Pan Books.

Havel R (2000) Summary report on new regulatory codes and criteria and guidelines: IAEA guidelines for WWER reactor coolant system integrity assessment. Nuclear Engineering and Design. Vol 196, 93-100

Hayes V & Bojcun M (1988) The Chernobyl Disaster. The Hogarth Press. London

Head, L., Atchison, J. and Phillips, C., (2015) The distinctive capacities of plants: re–thinking difference via invasive species. Transactions of the Institute of British Geographers, 40(3), pp. 399-413.

Head, L. and Muir, P (2006) Suburban life and the boundaries of nature: resilience and rupture in Australian backyard gardens. Transactions of the Institute of British Geographers, 31(4), pp. 505-524.

Herrmann R (2014) Fractional calculus: an introduction for physicists. World Scientific Co, Singapore.

Hinchliffe, S., (2007) Geographies of nature: societies, environments, ecologies. Sage.

Hinchliffe, S., (2008) Reconstituting nature conservation: Towards a careful political ecology. Geoforum, 39(1), pp.88-97.

Hinchliffe, S., (2013) Remaking emerging infectious diseases. Biosecurity: The Socio-Politics of Invasive Species and Infectious Diseases, p.199.

Hinchliffe, S. and Bingham, N., (2008) Securing life: the emerging practices of biosecurity. Environment and Planning A, 40(7), pp.1534-1551.

Hinchliffe, S. and Whatmore, S., (2006) Living cities: towards a politics of conviviality. Science as Culture, 15(2), pp.123-138.

Hinton TG, Alexakhin R, Balonov M, Gentner N, Hendry J, Prister B, et al. Radiation-induced effects on plants and animals: findings of the United Nations Chernobyl Forum. (2007) Health Phys.93:427–40.

Hitchings, R. and Jones, V., (2004) Living with plants and the exploration of botanical encounter within human geographic research practice. Ethics, Place and Environment, 7(1-2), pp.3-18. /

Hoefle S W (2006) Eliminating scale and killing the goose that laid golden egg? Transactions of the institute of british geographers. 31 238 - 243

Hoel, D.G. and Li, P., (1998). Threshold models in radiation carcinogenesis. Health physics, 75(3), pp.241-250.

Hodgson P.E (1999) Nuclear Power, energy and the environment. Imperial College Press

Holbert K & Murray R (2015) Nuclear Energy: An Introduction to the Concepts, Systems and Applications of Nuclear Processes. Elsevier Inc

Holloway, J., (2000). Institutional geographies of the New Age movement. Geoforum, 31(4), pp.553-565.

Hook. D (2001) Discourse, Knowledge, Materiality, History Foucault and Discourse Analysis. Theory & psychology 11.4: 521-547.

Hook D (2005) Genealogy, discourse, ‘effective history: Focualt and the works of critique. Qualiative Research in Psychology. 2, 3-31

Hooker, A. M., Bhat, M., Day, T. K., Lane, J. M., Swinburne, S. J., Morley, A. A., & Sykes, P. J. (2004). The linear no-threshold model does not hold for low-dose ionizing radiation. Radiation research, 162(4), 447-452.

HSE (2002) Taking account of societal concerns about risk - framing the problem. Research Report, vol 035, Health and Safety Executive

Huff, J., (2007). Industry influence on occupational and environmental public health. International journal of occupational and environmental health, 13(1), pp.107-117.

Hull M.S (2012) Documents and Bureaucracy. The Annual Review of Anthropology, Vol 41, 251-267.

Hutchinson R (2003) Weapons of Mass Destruction: The no-nonsense Guide to Nuclear, Chemical and Biological Weapons Today. Weidenfield & Nicholson, London.

Hyndman, J., (2007). The securitization of fear in post-tsunami Sri Lanka. Annals of the Association of American Geographers, 97(2), pp.361-372.

Iansiti E & Konstantionv L (1978) Nuclear Safety Standards (NUSS) Programme - Progress Report. IAEA Bulletin, Vol 20, no 5

Ilbery, B., Maye, D., Ingram, J. and Little, R., (2013). Risk perception, crop protection and plant disease in the UK wheat sector. Geoforum, 50, pp.129-137.

International Atomic Energy Agency (IAEA) (1956) The Stature of the IAEA. Accessed at https://www.iaea.org/node/9642

International Atomic Energy Agency (IAEA) (1996) RBMK Nuclear Power Plants: Generic safety issues. A publication of the Extra budgetary Programme on the safety of WWER and RBMK Nuclear Power Plants. IAEA-EBP-RBMK-04. ISSN 1025-2754

International Atomic Energy Agency (IAEA) (1999) Final Report of the Programme on the Safety of WWER and RBMK Nuclear Power Plants: A publication of the Extra Budgetary Programme on the safety of WWER and RBMK Nuclear Power Plants. Available at http://www-ns.iaea.org/downloads/ni/wwer-rbmk/wwer_15.pdf [Accessed 10/5/14]

International Atomic Energy Agency (IAEA) (2008). The international nuclear and radiological event scale. Information Series, International Atomic Energy Agency, Vienna, Austria, 4.

International Atomic Energy Agency (IAEA) (2012) Nuclear Power Reactors of the World. Reference data series no.2. IAEA-RDS-2/31

International Atomic Energy Agency (IAEA) (2015) APS-1 Obninsk Reactor Details. Accessed at http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=447.

International Commission on Radiological Protection (ICRP), (2006), Low-dose extrapolation of radiation-related cancer risk. Publication 99.

International Nuclear Safety Advisory Group [INSAG] (1992) The Chernobyl Accident: Updating of INSAG-1 Available at http://www-pub.iaea.org/MTCD/publications/PDF/Pub913e_web.pdf [10th January 2014]

International Nuclear Safety Advisory Group (INSAG) (1992) Safety Series: The Chernobyl Accident: Updating of INSAG-1. no.75 Accessed at http://www-pub.iaea.org/MTCD/publications/PDF/Pub913e_web.pdf

International Nuclear Safety Advisory Group (INSAG) (1996) Defence in Depth in Nuclear Safety: a report by the international nuclear safety advisory group. INSAG - 10. VIC Library Cataloguing in Publication data. Accessed at http://www-pub.iaea.org/MTCD/publications/PDF/Pub1013e_web.pdf

International Nuclear Safety Advisory Group (INSAG) (2011) A Framework for an Integrated Risk Informed Decision Making Process. A report by the International Nuclear Safety Group.VIC Library Cataloguing in Publication data. Accessed at http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1499_web.pdf

Jargin, S. V. (2011). Thyroid cancer after Chernobyl: obfuscated truth. Dose-Response, 9(4), dose-response.

Jarvis, D. S. (2007). Risk, globalisation and the state: a critical appraisal of Ulrich Beck and the world risk society thesis. Global society, 21(1), 23-46.

Jaworowski, Z. (1999). Radiation risk and ethics. Physics Today, 52(9), 24-29.

Jaworowski, Z. (2010). Observations on the Chernobyl Disaster and LNT. Dose-Response, 8(2), dose-response.

Jeggo, P.A., Pearl, L.H. and Carr, A.M., (2016). DNA repair, genome stability and cancer: a historical perspective. Nature Reviews Cancer, 16(1), pp.35-42.

Jensen, Per Hedemann. (1994) The Chernobyl accident in 1986-Causes and Consequences. Lecture at the Institute of Physics and Astronomy, University of Aarhus 30.

Jensen, R.H., Langlois, R.G., Bigbee, W.L., Grant, S.G., Moore, D., Pilinskaya, M., Vorobtsova, I. and Pleshanov, P., (1995). Elevated frequency of glycophorin A mutations in erythrocytes from Chernobyl accident victims. Radiation research, 141(2), pp.129-135.

Johns, F., & Werner, W. G. (2008). The risks of international law. Leiden Journal of International Law, 21(04), 783-786.

Jones III JP, Woodward K and Marston S A (2007) Situating flatness. Transactions of the Institute of British Geographers. 32, 264-76

Jones, R.M., Instone, L. and Mee, K.J., (2014). Making risk real: Urban trees and the ontological politics of risk. Geoforum, 56, pp.211-225.

Josephson P (2000) Red Atom: Russia’s Nuclear Power Program from Stalin to Today. W.H Freeman and Company. New York

Justi R & Gilbert J (2000) History and philosophy of science through models: some challenges in the case of 'the atom’. International Journal of Science Education, 22:9, 993-1009

Katona T.J (2010) Plant life management (PLiM) practices for water-cooled water moderated nuclear reactors (WWERs) in T.J Tipping P (Ed) Understanding and mitigating ageing in nuclear power plants: materials and operational aspects of plant life management. Woodhead Publishing, Oxford.

Jones, O. and Cloke, P., (2002) Tree cultures: the place of trees and trees in their place. Berg Publisher.

Kaliatka A & Uspuras E (2000) Benchmark analysis of main circulation pump tip events at the Ingalina NPP using RELAP5 code. Nuclear Engineering and Design 202, 109—118

Kaliatka A & Uspuras E (2002) Thermal-Hydraulic analysis of accidents leading to local coolant flow decrease in the main circulation circuit of RBMK - 1500. Nuclear Engineering and Design. Vol 217, issues 1-2, 91-101

Kaliatka A, Urbonavicius E, Uspuras E (2008) Approach to accident management in RBMK - 15000. Nuclear Engineering and Design. 238, 241 - 249

Karpan N (1998) First days of the Chernobyl accident. Private Experience. Available at http://www.rri.kyoto-u.ac.jp/NSRG/en/Karpan2008English.pdf [accessed 1/09/14]

Karpan N (2001) Trial at Chernobyl Disaster. Available at http://www.physiciansofchernobyl.org.ua/eng/books/Karpan/Chernobyl_trial.pdf [Accessed on 21/8/14]

Kathren, R. L. (1996). Pathway to a Paradigm: The Linear Nonthreshold Dose-Response Model in Historical Context: The American Academy of Health Physics 1995 Radiology Centennial Hartman Oration. Health physics, 70(5), 621-635.

Kelman, I. and Dodds, R., 2009. Developing a code of ethics for disaster tourism. International Journal of Mass Emergencies and Disasters, 27(3), pp.272-296.

Kesminiene, A., Evrard, A. S., Ivanov, V. K., Malakhova, I. V., Kurtinaitis, J., Stengrevics, A., ... & Cardis, E. (2008). Risk of hematological malignancies among Chernobyl liquidators. Radiation research, 170(6), 721-735.

Khabaz R (2012) Assessment of gamma-rays generated by the spontaneous fission source 252Cf using Monte Carlo method. Annals of Nuclear Energy. Vol 46, 76-80.

Kinser A (2001) Simulating Wet Deposition of Radiocesium From the Chernobyl Accident. Department of the Air Force Air University. Air Force Institute of Technology. Wright-Patterson Air Force Base, Ohio.

Kitchen G (2007) Immunology and haematology. Edinburgh, Mosby.

Klein M (1961) Max Planck and the beginnings of the quantum theory. Archive for history of exact sciences. Vol 1, issue 5, 459-479

Kostin I (2006) Confessions of a Chernobyl Reporter. Umbrage Editions

Knap A (1988) The Long-Range Atmospheric Transport of Natural and Contaminant Substances. NATO Advanced Science Institutes Series C: Mathematical and Physical Sciences - Vol. 297

Kopustinskas, V., Augutis, J., & Rimkevičius, S. (2005). Dynamic reliability and risk assessment of the accident localization system of the Ignalina NPP RBMK-1500 reactor. Reliability Engineering & System Safety, 87(1), 77-87.

Kortov V & Ustyantsev Yu (2013) Chernobyl accident: Causes, consequences and problems of radiation measurements. Radiation Measurements, vol 55, 12-16

Kovalchuk, O., Burke, P., Arkhipov, A., Kuchma, N., James, S.J., Kovalchuk, I. and Pogribny, I., (2003). Genome hypermethylation in Pinus silvestris of Chernobyl—a mechanism for radiation adaptation?. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 529(1), pp.13-20.

Kovalchuk, I., Abramov, V., Pogribny, I. and Kovalchuk, O., (2004). Molecular aspects of plant adaptation to life in the Chernobyl zone. Plant Physiology, 135(1), pp.357-363.

Kovan, D., (2006). Chernobyl: Transforming an icon. Nuclear News, 49(4), pp.42-47.

Kriz J (1995) Remembering X-rays. Science, vol 270, 934

Kumosov, V.A., Moiseev, I.K., & Tsurikov, E.P. (1995). Design of shelter - experience of planning and construction in 1986. Nuclear Energy Agency of the OECD (NEA): Organisation for Economic Co-Operation and Development.

Kupny V.I (1996) Chernobyl NPP's Shelter Site Yesterday, Today, and Tomorrow. Production Association P/O Chernobyl NPP, Ukraine. Available at http://inis.iaea.org/search/Search.aspx?q=28053753

Kurnosov V, Bagryanskii V & Moiseev I (1988) Entombment of Chernobyl. Soviet Atomic Energy. Vol 64, Issue 4, 299-306.

L'Annunziata & Michael F (2012) Handbook of radioactivity analysis. Elsevier Science, San Diego

Land, C. E. (1995). Studies of cancer and radiation dose among atomic bomb survivors: the example of breast cancer. Jama, 274(5), 402-407.

Lash S (2000) Risk Culture. In Adam B (ed) The Risk Society and Beyond. SAGE: London

Latour B (1987) Science in Action. Open University Press. Milton Keynes

Latour B (1990) Drawing things together in Lynch M and Woolgar S eds. Representation in scientific practice. The MIT Press, London 19-68

Latour B (1993) We Have Never Been Modern. Translated by Catherine Porter. Harvard College Press

Latour B (1994) Technical mediation - philosophy, sociology, genealogy. Common Knowledge, v4, no 2, 29 - 64

Latour B (1996) Aramis, or, The love of technology. Harvard University Press.

Latour, B., (1996). On actor-network theory: a few clarifications. Soziale welt, pp.369-381.

Latour, B., (1999). Pandora's hope: essays on the reality of science studies. Harvard University Press.

Latour, B., (1999). On recalling ANT. The Sociological Review, *47*(S1), pp.15-25.

Latour B (2005) Reassembling The Social: An Introduction into Actor - Network Theory. Oxford University Press, Oxford

Latour B (2013) An Enquiry into Modes of Existence: An Anthropology of the Moderns. Harvard University Press.

Latour, B. and Venn, C., (2002). Morality and technology the end of the means. *Theory, culture & society*, *19*(5-6), pp.247-260.

Laurier E & Philo C (1999) X-morphising: review essay of Bruno Latour's Aramis, or the Love of Technology.

Laurier E & Philo C (2004) Ethnoarchaeology and undefined investigations. Environment and Planning A, vol 36, 421-436.

Law J & Mol A (2001) Situating technoscience: an inquiry into spatialities. Society and Space, vol 19, 609-621

Law J (2002) Objects and Spaces. Theory, Culture and Society. vol 19,

Law J & Singleton V (2005) Object Lessons. Organizations, Vol 12, 331

Lee, J. C., & McCormick, N. J. (2012). Risk and safety analysis of nuclear systems. John Wiley & Sons.

le Blanc K, Rasmusson I, Sundberg B, Gotherstom C, Hassan M, Uzenel M & Ringden O (2004) Treatment of severe acute graft-versus-host disease with third party haploidentical mesenchymal stem cells. The Lancet, vol 363, issue 9419, 1439-1441

Lederman L (1996) Safety of RBKM reactors: Setting the technical framework. IAEA Bulletin.

Leitner H & Miller B (2006) Scale and the limitations of ontological debate: a commentary on Marston, Jones and Woodward. Transactions of the institute of British Geographers 32 116 - 125

Lemke T (2013) An indigestible meal? Foucault, governmentality and state theory. Distinktion: Scandinavian Journal of Social Theory. 8:2 43 - 64
Law J & Mol A (1995) Notes on Materiality and Sociality. The Sociological Review.

Lima, J., Trovisco, V., Soares, P., Máximo, V., Magalhães, J., Salvatore, G., Santoro, M., Bogdanova, T., Tronko, M., Abrosimov, A. and Jeremiah, S., (2004). BRAF mutations are not a major event in post-Chernobyl childhood thyroid carcinomas. The Journal of Clinical Endocrinology & Metabolism, 89(9), pp.4267-4271.

Lippert, R.K. and Walby, K., (2013). Policing cities: Urban securitization and regulation in a 21st century world. Routledge.

Liou K.N (2002) An Introduction to Atmospheric Radiation. Elsevier Science, Academic Press. San Diego

Limtanakool, N., Schwanen, T. and Dijst, M., (2009). Developments in the Dutch urban system on the basis of flows. Regional Studies, 43(2), pp.179-196.

Lorimer, J., (2007) Nonhuman charisma. Environment and Planning D: Society and Space, 25(5), pp.911-932.

Lunin G.L, Voznesensky V.A, Fedorov V.G, Rogov M.F, Berkovich V.M & Kukhtevich I.V. (1997) Status and further development of nuclear power plants with WWER in Russia. Nuclear Engineering and Design. Vol 173. 43-57

Lusted M (2011) The Chernobyl Disaster. ABDO Publishing Company. Minnesota

Lyubchenko, I.G., Matveev, I.V., Kosheleva, N.N. and Zamkov, V.N., (2003). On construction of a new safe confinement over the fourth Chernobyl reactor.

Lyubarskiy A, Kuzmina I, El-Shanawany M (2011) Advances in Risk Informed Decision Making - IAEA Approach. Nordic PSA conference, Johannesberg Castle. Sweden.

Malko MV. (2002). The Chernobyl reactor: design features and reasons for accident. Working paper, Genshiryoku Anzen Kenkyu Group (Nuclear Safety Research Group, Japan). Available at http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr79/kr79pdf/Malko1.pdf [10 April 2014].

Mara, W., (2010) The Chernobyl disaster: legacy and impact on the future of nuclear energy. Marshall Cavendish.

Martin E (2013) Physics for Radiation Protection, Third Edition. Wiley-VCH Verlag & Co. Weinhiem

Martins R (1997) Becquerel and the Choice of Uranium Compounds. Arch. Hist. Exact Sci, Vol 51, 67 - 819

Marples D (1986) Chernobyl and Nuclear Power in the USSR. MacMillan Press, London.

Marples D (1988) The Social Impacts of the Chernobyl Disaster. MacMillian Academic and Professional LTD London

Marris C, Langford I, and O'Riordan T (1998) A Quantitative Test of the Cultural Theory of Risk Perceptions: Comparison with the Psychometric Paradigm. Risk Analysis, Vol 18, no 5.

Marston S A (2000) The social construction of scale. Progress in Human Geography 219 - 42

Marston S A, Woodward K and Jones III J P (2007) Flattening ontologies of globalization: the Nollywood case. Globaliza-tions 4 1-19

Mattson, M.P. and Calabrese, E.J. eds., (2009). Hormesis: a revolution in biology, toxicology and medicine. Springer Science & Business Media.

McCormack, D.P., (2007) Molecular affects in human geographies. Environment and Planning A, 39(2), pp.359-377.

McGeachan & Philo (2013) Words. In SAGE handbook of Human Geography

Medvedev G (1993) No Breathing Room: The Aftermath of Chernobyl. BasicBooks, London

Medvedev Z (1990) The Legacy of Chernobyl. WW Norton & Company. New York.

Melsen A (2004) From Atomos to Atom: The History of the Concept Atom. Harper & Brothers, New York.

Meshkati, N. (2007). Lessons of the Chernobyl nuclear accident for sustainable energy generation: creation of the safety culture in nuclear power plants around the world. Energy Sources, Part A, 29(9), 807-815.

Miele, M., Murdoch, J. and Roe, E., (2005). 11 Animals and ambivalence. *Agricultural governance: Globalization and the new politics of regulation*, *17*, p.169.

Mohanakumar K (2008) Stratosphere Troposphere Interactions. Springer Science.

Mol A & Law J (1994) Regions, Networks and Fluids: Anaemia and Social Topology. Social Studies of Science, Vol 24, 641 - 662

Mortazavi, S. J., Ikushima, T., & Mozdarani, H. (2004). An Introduction to radiation hormesis. Site:< http://www. angelfire. com/mo/radioadaptive/inthorm. html>, access at, 18(05).

Morton, T., (2011) Here comes everything: The promise of object-oriented ontology. Qui Parle: Critical Humanities and Social Sciences, 19(2), pp.163-190.

Mothersill, C., & Seymour, C. (2014). Implications for human and environmental health of low doses of ionising radiation. Journal of environmental radioactivity, 133, 5-9.

Mould R F (1988) Chernobyl: The Real Story. Pergamon Press, Oxford.

Mould R F (2000) Chernobyl Record: The Definitive History of the Chernobyl Catastrophe. Institute of Physics Publishing. London.

Müller-Mahn, D. ed., (2012). The spatial dimension of risk: how geography shapes the emergence of riskscapes. Routledge.

Munipov V (1992) Chernobyl operators: criminals or victims. Applied Ergonomics, 23(5)

277
337-342

Müller, M., (2014) A half-hearted romance? A diagnosis and agenda for the relationship between economic geography and actor-network theory (ANT). Progress in Human Geography, p.0309132513518833.
Murdoch, J., (1998). The spaces of actor-network theory. Geoforum, 29(4), pp.357-374.

Murdoch, J., (2000). Networks—a new paradigm of rural development?. Journal of rural studies, 16(4), pp.407-419.

Murdoch, J., (2001). Ecologising sociology: Actor-network theory, co-construction and the problem of human exemptionalism. Sociology, 35(01), pp.111-133.

Murdoch, J., (2005). Post-structuralist geography: a guide to relational space. Sage.

Murdoch, J. and Marsden, T., (1995). The spatialization of politics: local and national actor-spaces in environmental conflict. Transactions of the Institute of British Geographers, pp. 368-380.

Murdoch, J., Marsden, T. and Banks, J., (2000). Quality, nature, and embeddedness: Some theoretical considerations in the context of the food sector. Economic geography, 76(2), pp. 107-125.

Murray R (2001) Nuclear Energy: an introduction to the Concepts, Systems, and Applications of Nuclear processes. British Library Cataloguing in Publication Data.
Murty K.L (2013) Materials' ageing and degradation in light water reactors: Mechanisms and management. Woodhead publishing Series in Energy.

Mythen G (2004) Ulrich Beck: a critical introduction to the risk society. Pluto Press, Chippenham and Eastbourne.

Mythen, G., (2016). Terrorism, risk and insecurity. Routledge Handbook of Risk Studies, p.282.

Mythen, G., & Walklate, S. (2006). Criminology and Terrorism Which Thesis? Risk Society or Governmentality?. British Journal of Criminology, 46(3), 379-398.

Mythen, G., & Walklate, S. (2008). Terrorism, risk and international security: The perils of asking'what if?'. Security Dialogue, 39(2-3), 221-242.

Naime, A. and Andrey, J., (2013). Improving risk-based regulatory processes: identifying measures to pursue risk-informed regulation. Journal of Risk Research, 16(9), pp.1141-1161.

Nash L (1956) The Origin of Dalton's atomic theory. Isis, vol 47, no 2, 101-116

National Council on Radiation Protection and Measurements (NCRP), (2002) Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation (NCRP Report No 136). J. Radiol. Prot., 22:331

NAS/NRC (1972) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. Washington, DC: National Academy Press. Available at http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/37/004/37004410.pdf

Newman, M.C., 2009. Fundamentals of ecotoxicology. CRC press.

Niehaus F & Lederman L (1992) International safety review of WWER-440/230 nuclear power plants. IAEA Bulletin.

Nikulina, A.V., Markelov, V.A. and Peregud, M.M., (1996). Zirconium alloy E635 as a material for fuel rod cladding and other components of VVER and RBMK cores (No. CONF-950926–). American Society for Testing and Materials, West Conshohocken, PA (United States).

Nisbet, A. and Woodman, R., (2000). Options for the management of Chernobyl-restricted areas in England and Wales. *Journal of Environmental Radioactivity*, *51*(2), pp.239-254.

Nosovsky, A (1995) Chernobyl Nuclear Power Station: past, present, and future. Uranium and nuclear energy: 1995. Proceedings

Nosovsky A (1995) Chernobyl Nuclear Power Station: Past, Present and Future. Uranium Institute Information Service. Accessed at http://dwb.unl.edu/teacher/nsf/C03/C03Links/www.uilondon.org/uiabs95/nosov.htm

Nuclear Energy Agency (1999) Beneficial Uses and Production of Isotopes. Accessed at http://www.oecd-ilibrary.org.ezproxy.lib.gla.ac.uk/nuclear-energy/beneficial-uses-and-production-of-isotopes_9789264174368-en

Nuclear Energy Institute [NEI] (2011) Chernobyl Accident and Its Consequences. Available at http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Chernobyl-Accident-and-Its-Consequences [14th April 2014]

OECD Nuclear Energy Agency (1995) Chernobyl: Ten Years On. Radiological and Health Impacts. Available at https://www.oecd-nea.org/rp/chernobyl/chernobyl-1995.pdf

Okun L.B (1987) Alpha, Beta, gamma –zeta: a primer in particle physics. Harwood Academic Publishers. London

Oliveira M (2013) Equilibrium Thermodynamic. Springer, Berlin

Olsson G (1991) Lines of Power, Limits of Language. Minneapolis University Press.

O'Malley P (2001) Policing Crime Risks in the Neo-liberal Era. In Stenson K and Sullivan R (ed) Crime, Risk and Justice Cullomption: Willan Publishing: 89-103

O'Malley, P. (2009). Governmentality and risk. Social theories of risk and uncertainty, 52-75.
Ormrod, J.S., (2013). Beyond World Risk Society? A Critique of Ulrich Beck's World Risk Society Thesis as a Framework for Understanding Risk Associated with Human Activity in Outer Space. Environment and Planning D: Society and Space, 31(4), pp.727-744.

Ouma S (2010) Global standards, local realities: Private agri-food governance and the restructuring of the Kenyan horticulture industry. Economic Geography 86: 197–222.

Ouma S (2012) Creating and maintaining global connections: Agro-business and the precarious making of fresh-cut markets. Journal of Development Studies 48: 322–334.

Partington J (1939) The origins of atomic theory. First published online 2006.

Pastel, R. H. (2002). Radiophobia: long-term psychological consequences of Chernobyl. Military medicine, 167(2 Suppl), 134-136.

Patterson, W. C. (1986). Chernobyl—the official story. Bulletin of the Atomic Scientists, 42(9), 34-36.

Paul W (2005) A History of Radiation Detection Instruments. Health Physics, Vol 88, Issue 6, 613 - 637

Pershagen, B. and Bowen, M., (2013) Light water reactor safety. Elsevier.

Petryna, A., (2013). Life exposed: biological citizens after Chernobyl. Princeton University Press.

Philo C (1991) Foucault's Geography. Environment and Planning D: Society and Space, vol 10, 137-161

Philo C (2011) Discursive life. In: Del Casion VJ, Tomas M, Cloke P, and Panello R (eds) Companion to Social Geography. Wiley - Blackwell, 363 - 384

Philo C (2011) A 'new Foucault' with lively implications, or 'the crawfish advances sideways'. Transactions of the insitutue of British Geographers. Vol 37. 4967 - 514

Philo, C., (2012). Security of geography/geography of security. Transactions of the Institute of British Geographers, 37(1), pp.1-7.

Pierides D and Woodman D (2012) Object-orientated sociology and organzing in the face of emergency: Bruno Latour, Graham Harman and the material turn. The British Journal of Sociology, Vol 63, Issue 4

Plukiene, R. and Cometto, M., (2005). Evaluation of the activity of irradiated graphite in the Ignalina Nuclear Power Plant RBMK-1500 reactor. Nukleonika, 50(3), pp.113-120.

Pratt C, Targeting NF-kB to prevent Radiation-induced Carcinogenesis. In, Pierce G, Mizin V & Omelchenko A (eds) (2013) Advanced bioactive compounds countering the effects of radiological, chemical and biological agents: strategies to counter biological damage. Springer

Ramberg B (1986) Learning from Chernobyl. Foreign Affairs, Vol 65, no 2, 304 - 328

Rhodes W & Stanley H (2008) Introduction to Radiation Protection: Practical Knowlege for Handling Radioactive Sources. Springer, London

Robbins, J., Merino, M.J., Boice, J.D., Ron, E., Ain, K.B., Alexander, H.R., Norton, J.A. and Reynolds, J., (1991). Thyroid cancer: a lethal endocrine neoplasm. Annals of internal medicine, 115(2), pp.133-147.

Roe, E., (2010). Ethics and the non-human: The matterings of animal sentience in the meat industry. *Taking-Place: Non-Representational Theories and Geography*, pp.261-80.

Rush, F.E., Thordarson, W. and Bruckheimer, L., (1983). Geohydrologic and drill-hole data for test well USW H-1, adjacent to Nevada Test Site, Nye County, Nevada (No. USGS-OFR–83-141). Geological Survey, Reston, VA (United States).

Saha K (2008) The Earth's Atmosphere: Its Physics and Dynamics. Springer, Berlin.

Salge, M. and Milling, P.M., (2006) Who is to blame, the operator or the designer? Two stages of human failure in the Chernobyl accident. System Dynamics Review, 22(2), pp.89-112.

Sanders, C. L. (2009). Radiation hormesis and the linear-no-threshold assumption. Springer Science & Business Media.

Sanderson, D.C.W., Allyson, J.D., Tyler, A.N., Scott, E.M., (1994). Environmental applications of air- borne gamma spectrometry. In: IAEA Technical Committee Meeting on the Use of Uranium Explo- ration Data and Techniques in Environmental Studies IAEA-TECDOC-827, pp. 71–91.

Sanderson D.C.W, Cresswell A.J, Allyson J.D, McConville P. (1997) Review of Past nuclear Accidents: Source Terms and Recorded Gamma-ray Spectra - Characterisation of the response of airborne systmes to short-lived fission products. Report No: DOE/RAS/97.001

Sanderson D.C.W, Cresswell A.J, Hardeman F & Debauche A (2004) An airborne gamma-ray spectrometry survey of nuclear sites in Belgium. Journal of Environmental Radioactivity, vol 72. 213-224

Santoro, M., Thomas, G.A., Vecchio, G., Williams, G.H., Fusco, A., Chiappetta, G., Pozcharskaya, V., Bogdanova, T.I., Demidchik, E.P., Cherstvoy, E.D. and Voscoboinik, L., (2000). Gene rearrangement and Chernobyl related thyroid cancers. British journal of cancer, 82(2), p.315.

Scerri, E., 2012. The periodic table. Handbook Philosophy of Science, 6, pp.329-38.

Schatzki T (2002) The site of the social: a philosophical account of the of the constitution of social life and change. Pennsylvania State University Press, State College PA

Shcherbak I (1989) Chernobyl: A Documented Story. The MacMillian Press LTD, London

Scott E.M, Sanderson D.C.W, Cresswell A. J, & Lang J.J (2000) Spatial scale and its effects on comparisons of airborne and ground- based gamma-ray spectrometry for mapping environmental radioactivity. Glasgow University. Accessed at http://www.spatial-accuracy.org/system/files/Scott2004accuracy.pdf

Scott, P.M., (2007) An overview of materials degradation by Stress Corrosion in PWRs. EUROPEAN FEDERATION OF CORROSION PUBLICATIONS, 51, p.3.

Seiler, R., Chawla, R., Gmür, K., Hager, H., Berger, H.D. and Böhme, R., (1988). Investigation of the void coefficient and other integral parameters in the PROTEUS-LWHCR Phase II program. Nuclear Technology, 80(2), pp.311-323.

Serres, M (1993) Statues. Flammarion, Paris

Shapin S & Schaffer S (1985) Leviathan and the Air-Pump: Hobbes, Boyle and the experimental life. Princeton University Press. Princeton

Shaw I (2010) WALL-E's World: animating Badiou's philosophy. Cultural Geographies, 17, (3) 391 - 405

Shaw I (2012) Towards an evental geography. Progress in human geography, 36 (5) 613 - 627

Shaw, I and Meehan, K., (2013) Force‐full: power, politics and object‐oriented philosophy. Area, 45(2), pp.216-222.

Shondell Miller, D., 2008. Disaster tourism and disaster landscape attractions after Hurricane Katrina: An auto-ethnographic journey. International Journal of Culture, Tourism and Hospitality Research, 2(2), pp.115-131.

Siegbahn A (1965) Alpha, Beta and Gamma Ray Spectroscopy. Vol 1. North-Holland Publishing Company.

Sinclair W (1958) The specification of radiation dose in publications. Radiology, 71.4: *575-576*

Sloterdijk P (2009) Terror From the Air. Semiotext, Los Angeles.

Slovic P (1987) Perception of Risk, Science, vol 236, 280-285

Slovic P (1992) Perception of Risk: Reflections on the Psychometric Paradigm. in Krimsky S & Golding D (eds) Social Theories of Risk. Prayer: Westport - 117-152.

Smith, D.K., Finnegan, D.L. and Bowen, S.M., (2003). An inventory of long-lived radionuclides residual from underground nuclear testing at the Nevada test site, 1951–1992. Journal of environmental radioactivity, *67*(1), pp.35-51.

Smith D, Dwyer J.R, Hazelton B.J, Grefenstette B.W, Martinez-McKinney G.F.M, Zhang Z.Y, Lowell A.W, Kelley N.A, Splitt M, Lazarus S.M, Ulrich W.U, Saleh Z.H, Cramer E, Rassoul H.K, Cummer S.A, Lu G, and Blakeslee R.J. (2011) The rarity of terrestrial gamma-ray flashes. Geophysical Research Letters, Vol 38

Smith N (1984) Uneven Development: locating globalization. Blackwell, Malden MA.

Smith N (1992) Contours of a spatialized politics: homeless vehicles and the production of geographical space. Social Text 33, 54 - 81

Smith N (1992) Geography, difference and the politics of scale. In Doherty j, Graham E. and Malek M, editors, Postmodernism and the social sciences, New York: st. Martin's Press, 57 - 79

Smith, R.G., (2003) World city actor-networks. Progress in human geography, 27(1), pp.25-44.
Spettel B & Palme H (1987) The contamination of Southern Germany with radioactive Cs from Chernobyl Fallout. Terra Cognita 7, 185-201

Sorenson K & Hanson B (2013) Making The Case for safe storage of used nuclear fuel for extended periods of time: combining near-term experiments and analysis with longer-term confirmation demonstration. Nuclear Engineering & Technology, vol 45, no4

Sorokin, N.M., Gabaraev, B.A. and Cherkashov, Y.M., (2006). Safe operation and life extension of RBMK plants. Nuclear engineering and design, 236(14), pp.1648-1656.

Spitzer, R. L., Gibbon, M. E., Skodol, A. E., Williams, J. B., & First, M. B. (1994). DSM-IV casebook: A learning companion to the Diagnostic and Statistical Manual of Mental Disorders—4th ed. American Psychiatric Association.

Stedwell C.N & Polfer N.C (2013) Chapter 1, Spectroscopy and Electromagnetic Spectrum. In Laser photodissocation and spectroscopy of Mass-separated bimolecular ions. Lectures Notes in Chemistry, vol 83, 1-20

Stoff, Michael B., Jonathan F. Fanton, and R. Hal Williams (1991) "The Manhattan Project.". Accessed at http://www.univie.ac.at/igl.geschichte/ash/Texte_fuer_Lehrveranstaltungen/Stoff.pdf

Surjan, A., Kudo, S. and Uitto, J.I., (2016). Risk and Vulnerability. In Sustainable Development and Disaster Risk Reduction (pp. 37-55). Springer Japan.

Tai C, Strande L, Hidetoshi S, Matthews M, Gordon C & Hewitt C (2008) Vascularised Bone Marrow Transplants. In Hewitt C, Lee A, Gordon C (eds) Transplantations of composite tissue allografts. Springer, New York.

Taylor P (1982) A materialist framework for political geography. Transactions of the institute of British geographers. 7, 15 - 34.

Tester, J.W., 2005. Sustainable energy: choosing among options. MIT press.

Theodorakis, C.W., Bickham, J.W., Lamb, T., Medica, P.A. and Lyne, T.B., 2001. Integration of genotoxicity and population genetic analyses in kangaroo rats (Dipodomys merriami) exposed to radionuclide contamination at the Nevada Test Site, USA. Environmental Toxicology and Chemistry, 20(2), pp.317-326.

Thomas, C.B., Nelson, D.O., Pleshanov, P. and Jones, I.M., (2002). Induction and decline of HPRT mutants and deletions following a low dose radiation exposure at Chernobyl. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 499(2), pp.177-187.

Thrift, N., (1996) Spatial formations (Vol. 42). Sage.

Truta L.A, Hofmann W, Cosma C and Dadulescu D (2012) Health Effects Attributed to Radon From the Perspective of the Linear No-Threshold Hypothesis. Phys. 58:S280–90

Tubiana, M. (2008). The 2007 Marie Curie prize: the linear no threshold relationship and advances in our understanding of carcinogenesis. International Journal of Low Radiation, 5(3), 173-204.

Tubiana, M., Feinendegen, L. E., Yang, C., & Kaminski, J. M. (2009). The Linear No-Threshold Relationship Is Inconsistent with Radiation Biologic and Experimental Data 1. Radiology, 251(1), 13-22.

Tyapkov, V.F., Chudakova, I.Y. and Alekseenko, O.A., (2011). Achieving more reliable operation of turbine generators at nuclear power plants by improving the water chemistry of the generator stator cooling system. Thermal engineering, 58(8), pp.655-659.

Tyler A.N (1994) Environmental Influences on Gamma Ray Spectrometry. PhD thesis. Glasgow University. Available at http://theses.gla.ac.uk/4893/1/1994TylerPhD.pdf

UNSCEAR (1962) Report of the United Nations Scientific Committee on the effects of Atomic Radiation. General Assembly, Seventeenth Session, Supplement no.16. Accessed at http://www.unscear.org/unscear/en/publications/1962.html

UNSCEAR (2000) Exposure and effects of the Chernobyl accident. ANNEX J Available at http://www.unscear.org/docs/reports/2000/Volume%20II_Effects/AnnexJ_pages%20451-566.pdf [accessed 10/9/14]

UNSCEAR (2008) Sources and Effects of Ionising Radiation. Volume 2, Annex D, Health Effects Due to Radiation from the Chernobyl Accident. United Nations Scientific Committee on Effects of Atomic Radiation. Volume 2. Accessed at http://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf

United Nations. Scientific Committee on the Effects of Atomic Radiation. (2000). Sources and effects of ionizing radiation: sources (Vol. 1). United Nations Publications.

United States Atomic Energy Commission (1955) Atomic Test Effects in the Nevada Test Site Region. Accessed at https://www.fourmilab.ch/etexts/www/atomic_tests_nevada/

United States Environmental Protection Agency (US EPA), (2008), EPA Radiogenic Cancer Risk Models
and Projections for the U.S. Population.

Urbonas, R., Uspuras, E. and Kaliatka, A., (2003). State-of-the-art computer code RELAP5 validation with RBMK-related separate phenomena data. Nuclear Engineering and Design, 225(1), pp.65-81.

Usbonas R & Kaliatka A (2007) Evaluation of weak heat conduction mechanism model for long term LOCAs in RBMK-1500. Nuclear Technology, vol 158, no1, 18-25

Ushakov, I.B. and Soldatov, S.K., (1993). An analysis of the health status of helicopter pilots who participated in the cleanup of the consequences of the accident at the Chernobyl Atomic Electric Power Station. Voenno-medit͡sinskiĭ zhurnal, (4)

van der Borst M & Schoonakker H (2001) An overview of PSA importance measures. Reliability Engineering & System Safety. Vol 72, Issue 3. 241-245

van der Hoeven, N., Aerts, J., van der Klis, H., & Koomen, E. (2009). An integrated discussion support system for new Dutch flood risk management strategies. In Planning Support Systems Best Practice and New Methods (pp. 159-174). Springer Netherlands.

Venuti, G.C., Risica, S. and Rogani, A., (1991). Radioactive caesium contamination in human milk in Italy after the Chernobyl accident. *Radiation protection dosimetry*, *37*(1), pp.43-49.

Virillio P (1983) Pure War. Semiotext: New York.

Wagemans C (1991) The Process of Nuclear Fission. Library of Congress Cataloging

Wallace B & Dobzhansky T (1959) Radiation, Genes, and Man. Henry Holt and Company. New York.

Wallner, A., Belgya, T., Bichler, M., Buczak, K., Dillmann, I., Käppeler, F., Lederer, C., Mengoni, A., Quinto, F., Steier, P. and Szentmiklosi, L., (2014) Novel method to study neutron capture of U 235 and U 238 simultaneously at keV energies. Physical review letters, 112(19), p. 192501.

World Nuclear Association (2012) Plutonium. Available at http://www.world-nuclear.org/info/nuclear-fuel-cycle/fuel-recycling/plutonium/ [14 April 2014]

Waskow A (1986) Light From Chernobyl CrossCurrents, 36(1), pp.1-4.

Weinberg, H.S., Nevo, E., Korol, A., Fahima, T., Rennert, G. and Shapiro, S., (1997). Molecular changes in the offspring of liquidators who emigrated to Israel from the Chernobyl disaster area. Environmental health perspectives, 105(Suppl 6), p.1479.

Whatmore, S., (2002). Hybrid geographies: Natures cultures spaces. Sage.

Whatmore, S., (2006). Materialist returns: practising cultural geography in and for a more-than-human world. Cultural geographies, 13(4), pp.600-609.

Whatmore, S. and Hinchliffe, S., (2003) Living cities: making space for urban nature. SOUNDINGS-LONDON-LAWRENCE AND WISHART-, pp.37-50.

Whatmore, S. and Hinchliffe, S., (2010) Ecological landscapes. In The Oxford Handbook of Material Culture Studies.

WhiteHead A (1979) Process and Reality. Free Press: New York

Williams, D. (2008). Twenty years' experience with post-Chernobyl thyroid cancer. Best Practice & Research Clinical Endocrinology & Metabolism, 22(6), 1061-1073.

Wong S (1998) Introductory Nuclear Physics, second edition. John Wiley & sons Inc. London.

Wynne, B. (1996). A reflexive view of the expert-lay knowledge divide. Risk, environment and modernity: towards a new ecology. Sage, London, 44-83.

Vaiserman, A. M. (2010). Radiation hormesis: historical perspective and implications for low-dose cancer risk assessment. Dose-Response, 8(2), dose-response.

Veissier, I., Butterworth, A., Bock, B. and Roe, E., 2008. European approaches to ensure good animal welfare. *Applied Animal Behaviour Science*, *113*(4), pp.279-297.

Yaroshinskaya A (1994) Chernobyl: The Forbidden Truth. Jon Carpenter, Oxford.

Yaroshinskaya A (2006) Chernobyl: A Crime Without Punishment. Transaction Publishers. London.

Yates S & Hiles D (2010) Towards a critical ontology of Ourselves'?: Foucalt, Subjectivity, and Discourse Analysis. Theory Psychology, 20, 52-77

Yoschenko, V.I., Kashparov, V.A., Melnychuk, M.D., Levchuk, S.E., Bondar, Y.O., Lazarev, M., Yoschenko, M.I., Farfán, E.B. and Jannik, G.T., (2011). Chronic irradiation of Scots pine trees (Pinus sylvestris) in the Chernobyl Exclusion Zone: dosimetry and radiobiological effects. Health physics, 101(4), pp.393-408.

Zykova, I. A. (2007). Environmental risk perception after Chernobyl. Cultures of Contamination. Research in Social Problems and Public Policy, 14, 205-221.