Securing Natural Gas: Entity-Attentive Security Research

FORMAN, PETER,JAMES

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Entity-Attentive Security Research

Peter James Forman

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Department of Geography
Durham University

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Abstract

Natural gas is a troublesome and 'wayward' material (Bridge, 2004; 396). Amongst other qualities, it is invisible, intangible, naturally odorless, highly inflammable, and constantly resistant to the forces that contain it. This thesis provides an account of how these qualities both introduce a series of insecurities to everyday social environments, and also make it a challenging material to govern. Specifically, I examine the way that security is performed around gas circulations in the UK's transmission and distribution pipelines, and I describe how a range of specialized security practices have been developed according to the particular challenges that gas's materiality presents.

In developing this account, I make two claims. First, I argue that performances of security cannot be adequately understood without attending to the specific qualities of the circulating elements around which it is practiced. Here I build upon Dillon's (1996) observation that security has tended to be treated as a noun that is independent of the elements that it is practiced in relation to. As a consequence, it has typically been framed as a broadly transferrable set of practices that can be more-or-less unproblematically applied to very different elements. I suggest that this abstraction has resulted in the further reduction of security into two broad practices: acts of circulatory filtration (in which risky elements are separated from flows of safe bodies, materials and things), and acts of circulatory maintenance (whereby security is performed by ensuring the continuity of particular circulations). It is my contention in this thesis that security scholars need to pay better attention to the ways in which the specific material qualities of circulating elements are generative of particular forms of securing practice. Indeed, by examining the way that security is performed around gas, I describe a series of practices that far exceed those described in

accounts that present security as a matter of circulatory filtration or maintenance.

My second claim is that the spaces and scales at which security is analyzed need to be expanded. I demonstrate how the critical security studies and energy security literatures have both tended to focus on security's practice within particular nodes, at the exclusion of the performances of security (and forms of insecurity) that develop across the journeys of circulating elements; as they move *between* nodes. Indeed, I suggest that circulation has often been reduced in these accounts to thin, straight, and featureless lines that are largely inconsequential for performances of security. I seek to trouble this reduction, following gas as it travels through the UK gas transport infrastructures, tracing the various forms of (in)security that develop across these journeys.

As a consequence of these two claims, security takes quite a different form in this account to its various depictions in the existing security literatures. I describe it as consisting of a series of ontological projects that are enacted across the lengths and breadths of gas's circulations, and through which the material reality of natural gas is constantly (re)organised in attempts to facilitate, 'compensate for', and 'cancel out' particular kinds of perceived potential phenomena (Foucault, 2007; 36). Significantly, these performances are shown to be structured, or 'programmed' (Latour, 1991), through the coming together of multiple interests that pertain to a variety of heterogeneous actors and manifold referent objects. Different interests are shown to come together across gas's journeys, and to undergo ongoing processes of negotiation that result in a variety of security performances, through which different imperatives are pursued. As such, I suggest that gas becomes 'modulated' (Deleuze, 1992) – it is constantly transformed from moment to moment, across the full duration of its circulatory journeys.

"A substance synonymous with fluidity and effervescence, gas is defined by unpredictable motion both at the molecular level and within popular culture, where the gaseous and ethereal serve as antonyms for the solidity and fixity of the terrestrial."

Bridge (2004; 396) "Gas, and How to Get it"

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List of Abbreviations

ANT	Actor-Network Theory
CWV	Composite Weather Variable
CIP	Critical Infrastructure Protection
CV	Calorific Value
DEI	Durham Energy Institute
EI	Energy Institute
ENA	Energy Networks Association
ERS	Engineering Research Station
GS(M)R	Gas Safety (Management) Regulations
GWh	Gigawatt Hours
HSE	Health and Safety Executive
IGEM	Institute for Gas Engineers and Managers
IPCC	Intergovernmental Panel on Climate Change
LDZ	Local Distribution Zone
LNG	Liquefied Natural Gas
LPA	Local Planning Authority
LRF	Local Resilience Forum
Mm^3	Million Cubic Meters
MRPS	Mains Risk Prioritization System
NTS	National Transmission System
OFGEM	Office for Gas and Electricity Markets
OPEC	Organization of the Petroleum Exporting Countries
PE	Polyethylene
PIG	Pipeline Inspection Gauge

SCADA	Supervisory Control and Data Acquisition
UKITT	UK Institute for Trenchless Technology
UKOPA	UK Onshore Pipeline Operators' Association

Statement of Copyright

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To Sarah, who now knows a lot about gas.

1

Introduction

"If you have a failure at 40 bar [on the UK's high pressure gas transport system], you have a bomb. It will just rupture, and if it is above ground it will blow bits for many, many tens of meters. So you will know about it. If it is an underground failure, it will blow a hole. […] This is a bomb. Don't ever forget that."

(Interview, Senior Engineer, National Grid - 9th April 2015)

I. Threats from the Underground

At 7.15am on the morning of the 10th of January 1985, an explosion took place in a block of luxury flats in Putney, Southwest London. It killed eight people, demolished six apartments, and shattered all nearby windows within a quarter of a mile radius (HSE, 1985). Only thirteen minutes earlier, a resident of Flat No. 12 had called the local gas distribution company to report a suspected gas leak (Ibid).

Gas's explosiveness is demonstrative of its vitality and energy. Whilst these qualities make it useful for heating homes, for cooking food and for generating electricity, they also introduce a series of threats to everyday social environments. Gas can injure bodies, claim lives and destroy property, and these threats are made more difficult to avoid by the ways that it evades human senses. It is a material that is invisible, intangible, and naturally odourless to humans, and it consequently presents particular difficulties for knowing where it is, how it is moving, and what forms of agency are available to it at any one point in space and time. It is also remarkably recalcitrant. It is lighter than air, so rises irretrievably unless it is contained, and like all gases, it is compressible, expanding or compacting to fill any volume. In the process, it exerts varying amounts of outwards force upon the walls that contain it, and if this force exceeds the limits of its containers, the gas will escape, potentially causing injury, loss of life, or damage to property.

A consequence of these challenging material qualities is that natural gas requires a highly specific set of securing practices to be performed around it at all times. Without the conduct of these practices, it could not be safely transported, nor could it be usefully consumed. As Bridge (2004; 396) describes, "[a] whole industry has emerged […] dedicated to corralling the waywardness and variability of gas and rendering it a commodity compliant with the workings of the market". Should these practices be disrupted – even for a moment – then the vitality, recalcitrance, and 'waywardness' of natural gas will overcome the structures that govern it; it either becoming diffused within the atmosphere, or accumulating in potentially flammable or explosive volumes.

Despite this, gas's combustibility is just one way in which it is perceived as becoming 'dangerous' (Dillon and Reid, 2001). Amongst various other perceived dangers, UK society has become reliant upon it. It is now one of the primary components of the country's energy mix, and is widely used for heating buildings, warming water, cooking food, manufacturing products and generating electricity. As such, numerous forms of social, political and economic function have come to rely upon its continued circulation. Without it, basic social functions such as heating homes, washing bodies and cooking food would face severe disruption. Vulnerable people such as the ill or elderly could die from exposure to the cold, and many actions that are dependent upon electricity (including lighting, manufacture, transport and communications) would be put under severe strain[1]. Due to the relative inertia of large energy infrastructures such as the UK's gas system (Haarstad and Wanvik, 2016), gas circulations could also not be quickly or easily replaced with circulations of other kinds of energy product. For the short to medium term at least, UK society will remain dependent upon its uninterrupted circulation.

As a result of these 'dangerous dimensions' (Dillon and Reid, 2001), a large variety of actors have become involved in governing gas's circulation at a range of scales – from the global to the molecular. From politicians to ground workers, local planning authorities to polyethylene pipes, a vast array of heterogeneous actors have become engaged in managing and regulating the circulation of gas on an everyday basis.

Whilst these ground workers and gas pipes may not possess the visual spectacle of body scanners, iris scans, passport controls, or the plethora of other border control checks that are currently deployed in our ever-vigilant contemporary world – and whilst their practices are rarely afforded the grandiose rhetoric that is commonly associated with performances of geopolitical security – it is my contention in this thesis that they must each be seen to be intricately involved in performing *security* around natural gas in different ways, at various points in space and time. For within their actions we can observe numerous attempts to "gradually compensate[…] for, check[…], finally limit[…], and, in the final degree, cancel[…] out" different forms of contingent phenomena[2] that relate to gas's circulation (Foucault, 2007; 37), and regardless of their apparent banality, these actions can thus be understood as constituting security practices.

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[1] Such strains would be particularly acute, given that electricity demand would rise in the short-term as members of the public turned to electric heating and electric stoves to replace functions that were previously enabled by by gas's circulation.

[2] These include explosions and supply shortages.

II. Research Agenda

This thesis explores the specifics of these gaseous security performances and examines how attempts are made to deal with the problematic material qualities of circulating natural gas. In the chapters that follow, I provide an account of the actors that implicate themselves in gas's governance, and discuss the different kinds of phenomena that these actors seek to influence by taking action upon gas's circulation. Central to creating this account is investigating how each actor perceives gas's ontological configurations to be productive of different kinds of (in)security at specific moments in space and time. It involves asking how gas, through its associations with other heterogeneous elements[3], comes to be seen to present different dangers, challenges and opportunities, according to the different perspectives of the actors that are involved in its governance.

Building upon this aim, I seek to examine the forms of action that these actors take upon gas's circulation, and the various ways through which they hope to secure against particular forms of perceived potential phenomena. I thus describe how security is practiced in relation to gas, documenting the efforts that are made to render it actionable in different ways, and exploring how its ontological constitution is variously altered so that particular kinds of gaseous event come to be facilitated, compensated for, or cancelled out.

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[3] The term 'element' is used in this thesis in the same way as it appears in the actor-network theory and assemblage literatures (Latour, 1996a, 1993; Law, 2000; DeLanda, 2006; Barad, 2007): as a constituent part of a larger relational arrangement (elements, under this definition, include humans). It should not be confused with the term 'element' as it appears in the recent literature on elemental materials that has been developed by authors such as Pete Adey, (2015a) and Derek McCormack (2015), or in terms of a chemical or 'natural' definition.

Agenda 1: Entity-Attentive Security Research

In investigating performances of gaseous security in this way, I seek to pursue two related agendas. The first involves challenging the way that objects, bodies and 'things' have featured in the academic literature on security to date. This is a thesis about a particular circulating material – natural gas. Yet its argument is also situated within a wider critique of the way that this literature has underappreciated the objects around which security is practiced.

As Dillon (1996) has observed, security has often appeared as a noun, but as he contends, this is not the case. He writes; security *"is not a noun that names something, it is a principle of formation that does things. It is neither an ontological predicate of being, nor an objective need, but the progenitor instead of a proliferating array of discourses of danger"* (p. 16). In appearing as a noun, however – as a thing that has been abstracted from the specificities of its practice – security has become depicted as a set of practices that are distinct from the elements that it is conducted upon, and that is therefore able to be practiced in a similar manner in relation to a variety of different objects. Regardless of whether the topic of security's concern is 'national security', 'economic security', or 'energy security', there is thus an assumption that the study of security in one context can help to inform the study of security in another.

Whilst I do not wish to vilify the search for similarities between security practices, I am concerned with how this abstraction has led to the specificities of circulating bodies, materials and things being overlooked in studies of security. Security's generalization across topics has led to it frequently being distilled into two different kinds of practice that work to obfuscate the way that the distinct qualities of these elements are deeply entangled in security performances. Either security is seen to involve efforts to filter circulations into one of two categories (those that are deemed to be inherently safe, or those that are potentially risky), or it involves attempts to maintain the smooth and efficient flow of people, objects and things. According to these two approaches, insecurity either stems from the inclusion of potentially hazardous elements (as according to a filtration perspective), or from the interruption of particular flows that are essential to the continued functioning of a given referent object (as according to a circulatory maintenance approach). Whether security appears as practices of filtration or circulatory maintenance however, the elements that are acted upon nearly always feature as passive entities that present little problem for security's performance. They never resist, break, spill, rupture, or act in any unpredictable way, and they also do not change whilst in motion, or transform during security's practice. From point of origin to eventual destination, they remain unchanged. The thing that arrives is always the same as it was when it left.

This is particularly the case for circulating materials. There has been some recognition of the way that bodies are performed and altered through security's practice (see for example, Mark Salter's (2007) work on confessing security subjects, or Nick Vaughan-Williams' (2015) work on the dehumanizing of detained migrants)[4], but studies of security in relation to objects have almost entirely overlooked the challenging vitality of these materials and the ways that they are transformed through security's practice. Energy – for this thesis is about a circulating energy product – has been similarly dematerialized. Whilst it is perhaps the circulating material that has received most attention from security researchers[5] to date, the literature relating to its circulation has almost totally erased its material specificities. As Bridge (2014: 3, citing Hildyard et al.

[4] Despite this, there is still little work on the security challenges that the vitality and resistance that is expressed by these bodies present.

[5] Much of this work has not been conducted by scholars from the field of 'critical security studies', but has developed in isolation.

2012) has observed; "wind, water, biomass, fossil fuels are all made equivalent under the banner of 'energy', ignoring the different affordances that each of these distinctive materialisations of energy provides". As a result, security has been overwhelmingly reduced to practices of circulatory maintenance that involve political and economic negotiations at the level of international geopolitics. The liveliness of circulating energy products has therefore disappeared from view.

In this thesis, I argue that we cannot hope to understand security performances unless we closely attend to these numerous lively, and potentially troublesome, qualities. As I demonstrate in the chapters that follow, the way that security is practiced depends upon the specific qualities of these different entities. The gas examined in this thesis has challenging material qualities – it is invisible, intangible and odourless, and it therefore evades easy observation and control. It is not passive. It exerts force upon pipe walls, and it escapes and explodes. It is also not fixed and immutable. Amongst the many changes that it may undergo during its travels, it slows down and speeds up, it expands and compresses, and it transforms chemically. It is thus a material that presents unique problems for its governance, and it consequently requires highly specific sets of security practices to be conducted around it in order to facilitate, compensate for, and cancel out, particular kinds of phenomena. Without understanding the qualities of natural gas and the challenges that it presents, we can barely begin to even scratch the surface of the way that security is performed in relation to this lively material.

Yet gas is not alone in being a vital and problematic circulating shape-shifter. Whilst its transformations may be particularly pronounced, *all* circulating entities possess different troublesome qualities, and all elements undergo ontological alterations across their circulatory journeys. These alterations may take the form of physically observable changes to their physical constitution, but they may also take the form of less visible changes to their relationships with other elements[6]. Through these various alterations, new ways of acting, and new kinds of relational phenomena may be opened up that become the focus of security's practice. It is thus only by recognizing the ability of these elements to relationally transform and to have consequences that we can ever come to adequately understand how security may be affected by their clogging up, igniting, breaking, freezing, melting, exploding, decaying, transforming, expanding, or various other affective expressions.

In addition to their challenging vitality, we also need to pay attention to the ways in which elements are *transformed* in and through security's practice. In contrast to studies that present security as being a practice through which elements may pass without mutating, I present security as an *ontological project* through which entities and their relations with other elements are specifically manipulated in order to facilitate, compensate for, or cancel out particular kinds of emergent phenomena. In the chapters that follow, I show how natural gas is repeatedly transformed throughout its circulation, in relation to different forms of gaseous phenomena that are seen to have the potential to emerge in different contexts. Across its journeys, it is dried, chemically altered, heated, compressed, and liquefied. It also has its relationships with other elements carefully manipulated in order to prevent the formation of particular forceful associations. In these ways, it becomes ontologically altered – different forms of relationally-produced agency being facilitated, compensated for, and cancelled out by altering its constitutive relations. Without understanding the way that circulating elements such as gas are transformed and why – how their

[6] Such transformative qualities may not be immediately obvious. For example, attempts are often made to 'cancel out' entities' transformative qualities through the design of circulatory infrastructures. Airline passengers, for instance, have any items that could potentially enable them to threaten other passengers removed from their persons prior to their boarding. In this way, particular kinds of agency and threatening phenomena are prevented from emerging mid-flight.

constitution shifts/is shifted and mutates/is mutated – I consequently suggest that we can understand very little about how security is actually performed. As such, I put forward a call for a form of more entity-attentive security research; a form of research that holds in focus the specific relational transformations undergone by circulating elements in and through security's practice in its attempts to facilitate, 'compensate for', 'limit', or 'cancel out' (Foucault, 2007) particular kinds of possible future.

Agenda 2: Circulations Beyond Nodes

My second agenda in this thesis is to advocate for the expansion of the sites and scales at which security's performances are studied. Despite a burgeoning academic interest in the ways that security is conducted in relation to circulations of different kinds (Dillon, 2005), studies of security's performance have tended to restrict their analyses to particular nodal sites through which circulations pass. Sites of analysis have included airports (Adey, 2004; Salter, 2008; Martin, 2010; Amoore and De Goede, 2005), maritime ports (Cowen, 2009, 2010), points of terrestrial border crossing (Coleman, 2005; Ackleson, 2005; Ribas-Mateos, 2015), control rooms (Peters, 2014; Adey and Anderson, 2011b), and even cashpoints and supermarket checkouts (Dillon and Lobo-Guerrero, 2008; Amoore and de Goede, 2008). Likewise, studies of energy security have tended to focus upon the national-scale nodes of production and consumption – energy's circulation between these nodes typically becoming erased in the process. In privileging such nodal locations however, I suggest that scholars have often overlooked the details and qualities of the circulatory journeys that elements undertake, including their routes, volumes, materialities forces, velocities and rhythms. They have also failed to engage with the way that these elements and their circulatory qualities may present challenges for security *between* nodes, and the various ways in which security consequently comes to be performed across the extents of their circulatory journeys.

In contrast, this thesis makes a case for attending to the full extents of these circulations. By following gas's circulations between nodal sites, I look to explore its circulatory qualities and its potential dynamism during its travels. In the process, I explore how these various qualities can come to present various kinds of opportunity and challenge for security's performance. Indeed, in the chapters that follow, I describe how gas's circulations are far more complicated than simple straight lines between two points, outlining how these various circulatory qualities are generative of a host of security concerns and possibilities that become the focus of attempts to compensate for them, cancel them out, or efficiently exploit them.

In following gas as it moves in these ways, I seek to document how security is continually performed across entities' circulatory journeys. Indeed, I suggest that limiting security's analysis to nodal sites betrays an assumption that security is only practiced within nodes; that once the human body has had its identification and luggage checked within airport security stations, then security's practice is finished – that body is rendered secure. Yet such an approach, I suggest, entirely overlooks how security's subjects are performed *whilst they are in transit*. In the chapters to come, I will show how gas's challenging material qualities depend upon particular practices of security being constantly performed around it *throughout its circulation*. Without these practices, I argue, it would not be able to be consumed, and it might come to realise certain of its potentially hazardous capacities.

Yet whilst I advocate attending to these performances of security that take place across elements' circulatory journeys, they are often not easily visible at first sight – particularly when they are incorporated into the design or architecture of systems of circulation in ways that pre-emptively 'compensate for' or exploit particular forms of threatening or opportune phenomena. Despite this, I suggest that they are ubiquitous. What may appear to be a simple door that separates a flight deck from a passenger cabin for example, may actually be the focal point for a complex set of design decisions and operational rules that have been carefully developed in an attempt to 'cancel out' the possibility of a repeat of the hi-jacking events that led to the attacks on the World Trade Centre (Department of Transportation: Federal Aviation Division, 2002)[7]. Other security practices may also be performed more dynamically, whilst in transit. Should a passenger show signs of threatening behaviour mid-flight for example, then a flight marshal might seek to 'cancel out' these threats by subduing that passenger[8]. Security is thus not limited to certain critical nodes – it is performed throughout the duration of entities' journeys in ways that are sometimes hard to see. Limiting our analyses to particular nodes therefore risks overlooking much of this securing work, and as a consequence, there is thus considerable scope to expand the sites and scales at which security practices are studied, scholars needing to spread their analyses out across elements' circulatory travels.

[7] Indeed, as can be seen in the debates that have followed the recent Germanwings airline crash and the role that the security protocols surrounding these doors played into this event, such practices may also be generative of new forms of insecurity (BBC, 2017).

[8] If it has been deemed pertinent for a flight marshal to board that flight in the first place. These two examples are also fairly remarkable, and risk drawing attention away from the proliferation of more mundane practices that are employed to produce secure subjects throughout the duration of travelers' journeys. Such practices may consist of seemingly banal actions of devices such as no smoking lights; the seatbelt signs that light up during turbulence, take-off and landing; the reminders to passengers to turn on flight modes on their smartphones; and even in the making available of flight socks in long haul flights that reduce the chance of passengers developing deep vein thrombosis. In each of these examples, attempts are being made to 'cancel out' and secure against certain forms of disruptive or threatening phenomena, and to make the circulation of bodies traveling by air as smooth and efficient as possible.

III. Conceptual Approach

In line with the first of these two agendas, I have tried to avoid committing to established ways of viewing security's actors, its practices, its referent objects, and the logics that it operates according to. This is not a thesis that fits neatly into conventional conceptual brackets such as 'national security', 'biopolitical security', or even 'energy security'. Instead, it begins with the object under study – natural gas – and follows this object along its various journeys, observing the different forms of action that are taken upon it, and investigating the multiple motivations and interests that lie behind these actions. In this way, security's actors, practices, referent objects and logics were allowed to emerge in an inductive manner from their empirical contexts, and different actors, practices, referent objects and logics were identified as a result.

As shall be discussed in later chapters, this approach has given rise to a number of deviations from conventionally accepted conceptualizations of security. Unlike discourse-based approaches such as the work on securitization (a body of work that understands security to consist of decisional speech acts that are undertaken by authoritative human figures, and through which exceptional situations are defined[9]), many different forms of human and material actor were brought into focus through this thesis's fieldwork. These actors were defined through the particular kinds of action that they took upon gas, but unlike many studies of security, such actions could not be limited to acts of defining exceptional phenomena and 'cancelling them out'. Instead, the acts observed here were often also productive, with different actors seeking to take action upon gas in ways that brought about particular forms of phenomena. In taking these actions, different actors could be seen to attempt to enhance the security of their individual interests.

[9] See the work of Barry Buzan, Ole Wæver and Jaap de Wilde. A good introductory text is: Buzan, Wæver and De Wilde (1998).

As such, the forms of security that are described in this thesis do not fit into a typical account of security as bordering, but in many ways share similarities with accounts of biopolitical security, in which the productivity of populations is sought through security's practice (Dillon and Lobo-Guerrero, 2008). Yet the practices of security observed here also did not precisely fit a biopolitical approach, for biopolitical accounts take as their referent objects a single object; species life. Within my fieldwork, I observed different actors taking action upon natural gas according to a proliferation of individual interests. These actors did not seek to enhance the security of species life per se, but instead pursued the security of their own referent objects. Such concerns were at times differently articulated – from the security of supply for different groups of people (national populations, regional areas, individuals) – to the economic security of individuals and businesses – to the security of global climate. Different actors were also found to be concerned with the security of multiple different referent objects at once, and to attempt to take actions upon gas in order to pursue these various agendas.

I have subsequently come to see security as being a performance that is conducted by a heterogeneous assemblage of bodies, materials, texts, images and 'things'[10]. This notion of performance and emergence (drawn from actor-network theory and the work on assemblages), I suggest is critical, for it can be used to highlight the 'indeterminacy' of the security structures and entities that become involved in security's practice (McFarlane and Anderson, 2011). Should the actors within security performances change, or should the way that

[10] The concept of the assemblage has become influential within human geography and within research on security in recent years. Influential authors include Gilles Deleuze and Felix Guattari (1987), Jane Bennett (2005); Manuel DeLanda (2006) and Colin McFarlane and Ben Anderson (2011). The term 'assemblage' is used to refer to a collectivity of heterogeneous elements that are united through a series of contingent relationships with one another. Power is not equally distributed across these assemblages, but neither is power centralized. Instead, it is seen to circulate between elements (Bennett, 2005).

these actors behave transform, then the way in which security is conducted will also change, with new forms of threatening phenomena potentially emerging as a result.

I consider the objects that become the focus of security's practices to be performed through these security assemblages. Natural gas is enacted through the specific arrangements of the socio-material assemblages that surround it, and as the elements within these assemblages and their relationships with the gas change, so the gas – and the potential phenomena that can emerge in relation to it – also transform. Security therefore involves the management of these assemblages. It entails the manipulation of gas's relations with other elements in highly specific ways that depend upon the way that the gas is ontologically configured at any one moment. I suggest that, by manipulating these relations, particular kinds of gaseous phenomena can be facilitated, compensated for, or cancelled out. Should the elements that are involved in these performances change however, or should the relationships between them transform, then the gas may come to hold a form that no longer ensures the security of its different governing actors' interests. As such, security's performance may break down, and particular kinds of threatening phenomena may consequently emerge.

This I suggest, is particularly significant for understanding security's performance in relation to circulating elements, for as gas moves, it comes into contact with new actors, and its existing relations change. These new actors may express different interests to the actors before them, and they may seek to alter gas's ontological arrangements in ways that satisfy their own definitions of security. In the process, new forms of emergent phenomena may consequently also unfold, and as such, security cannot be seen to be performed in a fixed and singular way across the extent of elements' circulations.

IV. Research Design

Of specific focus in this thesis are the circulations of natural gas that travel within the UK's onshore gas transport networks. Whilst gas's circulation could have also been followed beyond the UK mainland – as it travels under seas, in boats, or across continents – I have restricted my analysis to gas's UK circulatory journeys as a matter of practical necessity.

The UK's gas networks can be split into several more-or-less discrete systems that involve largely different sets of actors. The first of these handles gas's onshore arrival. Gas arrives onshore either through the high pressure undersea pipelines that are owned by extraction companies, or via liquefied form in shipping tankers. It then immediately enters one of seven processing terminals that are distributed around the UK's coastline, each of which work to chemically alter it to ensure that it meets the national gas quality regulations (see Gas Safety (Management) Regulations 1996). These terminal facilities are typically owned by companies such as Shell, Exxon Mobil, and Total.

From these processing terminals, gas then enters the National Transmission System (NTS). The NTS consists of a more-or-less linear network of pipes that transport it along the length and breadth of the country[11] in large volumes and at high pressure (figure 1). This system is owned and operated by National Grid, and can be thought of as being akin to a motorway network, in that it directs large volumes of gas to wide regional areas.

[11] The NTS does not directly serve Northern Ireland, but provides gas to it and the Republic of Ireland via an interconnector. Northern Ireland's distribution network is only relatively small. It is mostly owned by Phoenix Natural Gas, which serves the Greater Belfast and Larne area. In contrast, the Republic of Ireland has a more extensive distribution network, operated by Bord Gais (see figure2).

From the NTS, natural gas then enters one of five local distribution networks[12]. Each of these networks is owned and operated by a separate private company (figure 2), and they can be thought of as being the gas industry equivalent of the UK's A-roads – they take gas out of the NTS and distribute it to homes and buildings across regional areas. These systems are necessarily more rhizomatic than the NTS, due to the way that they feed the consumption habits of a vast number of dispersed consumers. They consequently transport the gas in much smaller volumes and at much lower pressures across streets, under peoples' feet, and into homes and businesses.

It is useful to briefly note here the history of these distribution networks, for unlike much of the UK's gas infrastructure (which was installed in the late 1960s and early 1970s, when natural gas from the North Sea was first introduced as a commercial energy product), many of the distribution networks contain legacy pipes that were previously used in 'town gas' systems. These systems were much smaller, involving the distribution of a type of manufactured gas to consumers across small, localized networks[13]. During the development of the NTS however, these networks were connected up and converted to run on natural gas. This history is significant because, as shall be explored in later chapters, their ageing design continues to present particular challenges for gas's governance in the contemporary context.

[12] There are 23 NTS off-take points around the country. Some off-takes also serve large consumers such as power stations and factories.

[13] Town gas was a methane-based gas that was produced by baking coal in isolation from oxygen. It was first commercially introduced to the UK at the beginning of the 1800s, and it is unlikely – but possible – that some of the pipework within these systems dates as far back as to this period.

Figure 1 - Map of the UK National Transmission System, courtesy of National Grid 2015 (does not directly serve Northern Ireland – see footnote 11)

Figure 2 - Map of the Distribution Networks in the UK and Republic of Ireland, courtesy of National Grid 2015 (Northern Ireland distribution network excluded due to size – see footnote 11)

Research Scope

In addition to focusing my analysis on gas's travels across the UK mainland, further analytical cuts were made for similar practical reasons. Gas's journeys through the NTS were followed extensively in this research, but given the time needed to gain permissions to work with each distribution company, and given the similarities in many of their practices, my analysis of gas's travels within local distribution networks has been limited to just one system; the network that serves consumers in the North of England, and that is operated by Northern Gas Networks. For the same reasons, a single processing terminal was visited during this thesis's fieldwork – the terminal facility owned and operated by Shell in St. Fergus, Scotland.

Research Objectives

Within the scope of this research, I sought to trace gas along the full extents of its circulatory journeys. Rather than constrain my analysis to particular nodal sites, I followed the gas as it travelled, conducting fieldwork according to three objectives that relate to the research agendas outlined earlier. These objectives were:

1) ***To identify the heterogeneous actors that become involved in gaseous security performances***

2) ***To document the circumstances and logics under which securing action is considered necessary and is undertaken upon circulations of natural gas***

3) To observe and document the various practices that are employed to render natural gas 'known' and 'secure' throughout the duration of its circulations

I designed these objectives to explore the way that different actors come to be involved in gaseous security performances along their circulatory journeys, and to investigate the manner in which they became involved in performing security and why. At every stage in gas's journeys, I sought to identify the different associations that gas developed with other elements, and I documented the different forms of action that came to be taken upon it. I also interrogated the logics and motivations behind these actions. Close attention was paid to the way that gas came to be perceived as being productive of particular kinds of opportunity and threat throughout its journeys, and also to the ways in which its specific material qualities necessitated specialised techniques for its governance. A more detailed description of these objectives, and of the design of the research process can be found in chapter 3.

Research Methods

Methodologically, my approach was heavily influenced by the work of so-called 'follow the thing' studies (Cook, 2004; Christophers, 2011; Cook and Harrison, 2007), and also by the work on actor-network theory (see Latour, 2005; Callon, 1986a; Law, 2007). It involved identifying the routes that gas takes as it circulates across the UK, and then "follow[ing] the connections" (Latour, 2005; 175) that it formed with other elements throughout its journeys. By conducting interviews with the operators of pipelines, and by organizing numerous site visits to factories, company offices, control rooms, and pipelines, I developed a list of the different heterogeneous associations that gas formed (and could potentially form) across its circulatory routes. This list was also further expanded through the analysis of documentary materials that related to gas's governance, found either online, or in industry archives.

Perhaps most useful in these initial stages of tracing gas's circulatory journeys and associations were my early interviews with pipeline operators. By sitting down with practitioners and tracing gas's journeys through pipelines using maps, the various devices, measurements, actions, opportunities and risks that become wrapped up in the circulation of gas at different points in space and time could be systematically identified. Site visits also helped me to expand this list, for any relations that were not mentioned in interviews could often either be inquired about when observed in person, or interviewees would be reminded of them through their physical presence.

As new elements and associations were identified through these different methods, I then observed and interrogated the relations that they formed with natural gas in order to "learn from them not only what they do, but how and why they do it" (Latour, 1999; 19). Such practices were again largely conducted through site visits and interviews, and these methods enabled me to observe the various actions that were taken upon gas's circulation, and permitted me to interrogate the actors involved in a way that allowed me to assess the logics behind their actions and the different kinds of gaseous phenomena that they perceived as being possible to emerge at particular moments.

By following gas in these ways, it has been possible to construct the following account of how gas's circulation is secured in a UK context. In this thesis, I outline the ways that gas comes to present particular forms of threat and opportunity at different points in its circulation, and I document the different forms of action that are consequently undertaken upon it to render it actionable, and to facilitate, compensate for, and cancel out, particular kinds of gaseous phenomena.

V. Outline of Chapters

In chapter 2, I review the current security literature that relates to the governance of circulations. I take three conceptual slices through this work (security's spatialities, its logics, and its relationship with materials), and through these slices, I identify a number of analytical shortcomings that form the basis for the research agendas of this thesis. These shortcomings are also shown to share many similarities with those found in the related, but largely discrete, field of energy security; a body of work that this study also hopes to speak to through its analysis.

In the first section on spatialities, I draw attention to how this literature's current pre-occupation with circulation has opened security up to analysis at different spaces and scales. Yet whilst this work has been extremely productive, I argue that there remains a tendency to overlook the performances of security that take place across the duration of these circulations; researchers instead privileging nodal sites such as airports and points of border crossing. In doing this, I argue that the way in which security comes to be performed in relation to bodies, materials and things, across their circulatory journeys, has often been ignored.

In the section on logics, I then describe how a tension exists between the literatures that relate to a logic of continuation, and a logic of productivity. I demonstrate how these two logics might be usefully brought into conversation. Specifically, I draw attention to how the work on continuation imagines the protection of multiple forms of referent object but excludes practices of security that are not actions that produce exceptional decisions, and I then hold this in contrast with the work on biopolitical productivity, which adopts an expanded view of what constitutes a security practice, but limits itself to a singular referent object: populations. I consequently suggest that it should be possible to simultaneously appreciate multiple referent objects at the same time as adopting a broader definition of security practices.

In the chapter's final section, I then explore the way that the roles of materials within security performances have been conceptualised to date. Whilst this literature has been significantly rematerialized in recent years, I highlight how it still demonstrates a tendency to overlook the vitality of materials within practices of circulatory security. In particular, I suggest that the materials in circulation have often been assumed to be passive and inert in this work, and security has consequently featured as a set of practices that relate to circulatory maintenance or filtration within particular nodal sites of security's performance.

In chapter 3, I move on to describing the methodological framework for this thesis. Drawing on the observations from the previous two chapters, I establish the research agenda for this thesis, and outline a series of research questions. I then describe in detail the actor-network theory (ANT) inspired approach that was adopted for this study, discussing how ANT provides valuable tools for overcoming the challenges that natural gas presents for conducting a traditional 'follow the thing' study. In particular, I describe in this chapter how the buried quality of the UK's national gas infrastructure obstructed my attempts to follow the gas, and consequently liken the approach I adopted to to burrowing, rather than following.

In chapter 4, I begin my empirical analysis. Here, I explore the unique challenges that natural gas presents for security governance, highlighting how gas's inability to press upon human senses unless it is held within highly specific relational arrangements has led to difficulties for its governance and commercialization. I describe how a complex security apparatus has been developed around the circulation of natural gas to overcome these challenging material qualities, in order to render the gas knowable and actionable in different ways. In the process, I demonstrate how two different forms of 'map' are developed to visualise gas's fields of possible relations, such maps enabling action to be taken upon the gas and for potential gaseous phenomena to be managed.

The first of these maps constitute what I call 'blueprints'. These are more-or-less durable stabilizations of knowledges of gas's potential associations and connected phenomena. They provide a point of reference against which gaseous phenomena can be identified, and help security actors outline the associations that lead to the emergence of these phenomena.

The second type of map takes the form of 'snapshots'. These are context-specific, 'in the moment', visualizations of gas's immediate relations. I describe how a series of snapshots are constantly produced through security apparatuses, and demonstrate how these snapshots are compared against gaseous blueprints in order to identify particular phenomena whilst they are in the midst of their emergent becoming. As gas begins to actualize particular configurations of associations, I argue that attempts are made to trace out the phenomena they could lead to, efforts subsequently being taken to manipulate gas's relations in ways facilitate, compensate for, or cancel out, particular kinds of gaseous event before they actualise.

In chapter 5, I then turn to critique the way that circulations have featured within the literature on security. Such circulations, I argue, have consistently appeared as featureless, linear lines that pass between two or more points. In opposition to this depiction, I detail some of the specific qualities of gas circulations, and describe how these qualities can come to present particular challenges for gas's governance. Drawing upon the literature on mobilities (and in particular the work of Cresswell, 2010), I identify six qualities of gas circulations that, at different times and in different places, present particular challenges for security's practice. These qualities include: gas's paths and circuits, its volume, its materialities, the forces that operate upon it (and the forces that it exerts), its velocity, and its rhythms. Each of these qualities is shown to become entangled within the practices of security that are performed around gas as it is moving at different moments in space and time.

Developing upon the arguments made in the previous two chapters, chapter 6 then explores the way in which security can be understood to consist of projects of ontological manipulation that are conducted across the length of gas's circulation. As gas circulates, it develops new associations and forms of agency, and encounters new elements that each have their own particular interests. I describe how security consequently becomes 'programmed' in different ways to match the negotiated interests of these different interested parties. Such programming involves the careful alteration of gas's socio-material relations: relations that condition the forms of gaseous phenomena that can emerge in the future. I explore in detail how gas's relationally-constituted reality is thus carefully reconfigured in specific ways in order to facilitate, compensate for, and cancel out certain phenomena. Five specific practices are identified in particular; relational distancing, relational blocking, the alteration of gas's relations of interiority, the creation of relational reinforcements, and the configuration of indicative relations. I show how each of these different practices are employed in different ways and at different times to modulate gas; to differentially perform it according to the various actors and interests that become involved with it in its circulation.

In chapter 8, the thesis's conclusion, I then turn to review the contributions that this thesis makes to the existing literatures on security. I return to the question of the circulating entity; the way that bodies, materials and things have tended to be underappreciated in these literatures, and reiterate how we cannot adequately attend to security's practice without recognising the challenging vitality of these elements, and the ways that these elements and their various qualities become ontologically manipulated across the extent of their circulatory journeys. I finish with a discussion of the possible next steps for entity-attentive security research.

2

Securing Circulations

"What distinguishes the new security problematic in the first instance is therefore the primacy of the preoccupation with global/local 'circulation'. Circulation in this context means every conceivable kind of circulation or flow of peoples and things, of energy and finance, of water and food, of capital and information, of images and discourses, of science and technology, of weapons and ideas, of drugs and of sex (AIDS to prostitution), of microbes and diseases. In short, the new global security problematic is concerned with the circulation of everything" (Dillon, 2005; 2)

I. Introduction

As is acknowledged by Dillon in the extract above, circulations have become an increasingly prominent concern within contemporary practices of security. This concern has been borne out of two factors. The first has been an increase in awareness for the ways that the global circulation of bodies, food, water, energy, finance, information, consumer products, and waste constitute "a condition of possibility for the promotion and protection of a liberal way of life" (Lobo-Guerrero, 2008; 220), and the second has been an enhanced appreciation for the capacity of circulations to contain hazardous elements that might undermine the stability of social structures (including 'dangerous' human bodies such as the 'terrorist' or the 'illegal immigrant', as well as nonhuman elements such as bombs, narcotics and pathogens).

In response to these concerns, a large interdisciplinary security literature has developed around the topic of circulatory security. Such studies have attended relation to a variety of circulations, including (but not limited to) the movement of bodies by air (Adey, 2004; Martin, 2010; Kirschenbaum, 2013; Amoore and

Hall, 2009), land (Ackleson, 2005; Coleman, 2005) and by water (Rajaram, 2008; Peters, 2014; Peters and Turner, 2015; Mountz, 2015), in addition to the movement of such diverse 'things' as cargo containers (Cowen, 2010, 2009), finance (de Goede, 2012; Langley, 2014; Aitken, 2011; Boy, Burgess and Leander, 2011), luggage (Adey, 2004), pathogens (Elbe, Roemer-Mahler and Long, 2014; Elbe, 2007; Hinchliffe and Bingham, 2008; Bingham and Lavau, 2012; Clark, 2013b), and narcotics (Ackleson, 2005; Bourne, 2015; Grayson, 2008).

As with any sizable interdisciplinary literature however, the field of security studies has witnessed the development of a range of intellectual positions, with differing perspectives on topics such as; the spatial dimensions of circulatory (in)security; the constitution of security's referent objects; the constitution of security actors and security practices; the logics that drive security's performance; and the extent to which materials may play a role in security performances. In this chapter, I provide an overview of the critical security studies literature that specifically relates to circulation. I identify three areas in which intellectual controversy has arisen: the spatialities of (in)security, the logics through which security operates, and the roles of materials in security performances. Each of these topics is then used to structure a separate section of this chapter, with areas in need of further critical development being outlined in the process. I conclude by describing the ways in which these observations underpin the research agendas of my thesis.

Section II explores the ways in which space has been conceived in this literature. I show how the current emphasis on circulation has introduced new geographical perspectives to the study of (in)security, and whilst I take note of particular exceptions (c.f. Amoore, 2006; Vaughan-Williams, 2010; Cowen, 2009; 2010), I highlight the overwhelming preoccupation of this literature with centralised nodal sites, at the expense of studies of security's performance across the extent of elements' circulatory journeys.

In section III, I review the logics through which security is seen to operate in relation to circulations. I begin by describing the literature that frames security as a project of *survival*, before moving on to discuss other approaches that are concerned with the logics of *continuation* and *productivity.* For each of these perspectives, I compare the way that security's actors and practices have been differently defined, and place emphasis on how security is increasingly regarded as a relational project that consists of multiple interactions between dispersed heterogeneous elements. I conclude this section by developing a provisional framework for conceptualising security, bringing together aspects of the work relating to the logics of continuation and productivity to outline a position in which multiple referent objects are recognized, and in which security appears as a set of productive (rather than simply protective) practices.

Finally, in section IV, I describe the ways that materials have featured in these studies. I identify four main roles that have been prescribed to matter in this literature; architectures, decision makers, obstacles, and travellers. I highlight the continuing tendency of this work to downplay the vitality of these materials, and in particular, I draw to attention the way that scholars continue to overlook the transformations materials undergo as they travel. This, I suggest, is due to a tendency to focus on the assemblages that govern these circulations, instead of the particular qualities and agencies of the entities in circulation.

By developing my analysis along these three lines, I conclude the chapter by arriving at the two central agendas of the thesis. First, I describe the objective of providing an analysis of security that closely attends to the specific qualities and vitality of entities, and second, I justify the expansion of security's analysis to spaces of circulation beyond nodal sites.

II. Spatialities

Security studies scholars' recent increased interest in circulation has been broadly situated within a wider inter-disciplinary agenda to increase the depth and breadth of security's conceptual and empirical framing. With regards to depth, many scholars have attempted to expand their analyses beyond the confines of traditional accounts that position the nation state as the primary referent object of security's practice (the state being perceived as that which is at threat and must therefore be secured), to instead look at a plurality of referent objects, including (but not limited to): economies (Walker and Cooper, 2011; Aitken, 2011), climates (Dalby, 2014; Barnett, 2003), natural environments and ecological systems (Dalby, 2009, 2002; Hodson and Marvin, 2009), religions (Laustsen and Wæver, 2003; Eroukhmanoff, 2016; Kent, 2006), supply chains (Cowen, 2009) and human individuals (Jones, 1999; Duffield, 2006). In terms of breadth, attempts have been made to incorporate sources of insecurity that exceed traditional focuses on foreign military forces, with greater attention being paid to the multiplicity of threats that emerge from such diverse spheres as political arenas, economies, societies and environments (Peoples and Vaughan-Williams, 2010). Collectively, these expanded accounts of security have become grouped under the banner 'critical security studies'[14] (Ibid).

[14] The term 'critical' is used only as a linguistic device to indicate a shift away from traditional state-centric accounts (rather than to suggest that traditionalist studies are universally acritical). The label 'critical security studies' is also intended to refer to the general orientation of this work towards a questioning of the constitution of security and its referent objects, rather than to imply a singular coherent set of theoretical approaches (Peoples and Vaughan-Williams 2010).

The development of a critical security agenda has led to multiple re-imaginings of the spaces and scales of (in)security. Rather than geographical focus being restricted to the territorial outlines of nation states, and sources of insecurity being seen to operate only upon these territorial limits, scholars have broadened the geographical scope of security's analysis to look both within and beyond the borders of the nation state, examining multiple referent objects that occupy very different spaces and scales. Moreover, in widening the sources of insecurity under consideration beyond military forces, such approaches have documented a variety of threats that possess very different origins and spatial characteristics. Geographers' interest in security has consequently burgeoned since this critical turn, with researchers from across the discipline now working to explore the "uneven and entangled geographies of security and insecurity [that can be] located at a range of spatial scales and/or traced across a host of different networks spread far and near across the globe" (Philo, 2012: 2).

Yet it has not simply been the progression from traditional accounts that has intrigued human geographers. Whilst the origins of the critical security agenda are often cited as being located in the international political context that followed the Cold War and the collapse of the Soviet Union (c.f. Buzan, 1997; Krause and Williams, 1996; Walt, 1991; Collins, 2016; Baldwin, 1995), much of the geographical work on security developed significantly later, largely as a response to the 2001 attacks on the World Trade Centre. As Dillon (2005) has documented, these attacks generated a vastly increased awareness of the ways in which global circulations can create insecurity. Indeed, whilst such circulations are nothing new, their widespread prioritization within security agendas, and the generalized expansion of security to cover all forms of global circulation, is distinctive of the contemporary period, and has since become a major feature of what Dillon calls 'the new global security problematic' (p.2). It is this emphasis on circulation, I suggest, that has provided the catalyst for geographers' growing interest in security.

In the global security problematic, circulations are regarded as deeply enmeshed within, and productive of, the contemporary social world. As Dillon (2005) puts it:

"In a systematically interdependent world everything is connected or, in principle, is able to be connected, to everything else. Therefore, everything now matters. The smallest perturbations or anomalies in one system of circulation have the potential to cascade rapidly into large-scale crises affecting very many other local and global systems of circulation" (p.2).

As such, social existence is predicated upon global circulations of various kinds of 'stuff' (bodies, food, water, energy, manufactured products, data, waste and so forth), and insecurities stem from two sources: turbulence in circulations that may place stress upon, or directly undermine, the functioning of essential societal systems[15]; and the potential of these circulations to contain threatening bodies and things that, through their unregulated travel, may interfere with or destabilize the functioning of these systems. In these two ways therefore, circulations have become framed as major sources of insecurity that permeate practically all aspects of contemporary everyday life. Moreover, it is because of these two kinds of insecurity, I suggest, that security has often become framed as either a set of practices that are focused around filtering out flows of threatening entities from circulations that are perceived to be harmless, or as a set of practices that work to maintain the smooth, efficient, and uninterrupted flow of 'stuff'.

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[15] An example of such an approach is provided by Edensor (2010) who describes how "the indefatigable maintenance of largely invisible key flows of water, electricity, gas and telephony is vital to secure the security and stability of the city" (p.3).

This acknowledgement of the pervasiveness of circulations within the fabric(s) of social life, and of their increased enrolment within contemporary security agendas, has opened these security performances up to extremely broad geographical analysis across multiple spheres and scales. Geographical research has included studies of (in)security in relation to the nation state (Graham, 2012b; Mountz, 2013), populations (Sparke, 2006; Adey, 2009), urban environments (Hodson and Marvin, 2009; Graham, 2012a, 2010b; Coward, 2009), and individual bodies (Amoore and Hall, 2009), and interest has been drawn from across the discipline, geographers from different sub-fields exploring circulatory security in relation to such diverse topics as economics (Boy, Burgess and Leander, 2011), development (Essex, 2013), culture (Prout, 2009), politics (Amoore and de Goede, 2008), and human health (Bingham and Lavau, 2012; Elbe, Roemer-Mahler and Long, 2014).

Within this work, security has most commonly been engaged with through a post-structuralist lens, network-based conceptual approaches such as those developed in the work on actor-network theory (Callon, 1986a; Law, 2007; Latour, 2005) and assemblages (Deleuze and Guattari, 1987; DeLanda, 2006; Dittmer, 2013; McFarlane and Anderson 2011) featuring particularly heavily. Such network approaches have gained popularity mainly because they provide "a useful way of thinking about how spatial relations come to be wrapped up into complex networks"[16] (Murdoch, 1998: 357), thereby enabling scholars to understand how circulations connect up with, and come to structure, the fabric(s) of social life. Indeed, most such studies share a conceptualization of space that consists of sets of contingent relations between heterogeneous elements that always retain the potential to shift and transform (Callon, 1986a). Rather than perceiving space as a pre-existing or absolute container for action,

[16] Such networks, Latour (1999) reminds us, should not be confused with commonplace definitions that consider networks as fixed or rigid technical structures in which actors are transported but are not deformed. Rather, these approaches emphasize the contingent qualities of networks and their potential for transformation.

or as a passive backdrop against which social phenomena play out, they regard it as phenomenal or emergent; as existing as an outcome of constantly-developing relationships between heterogeneous elements. Circulations (which themselves are also the products of networks of contingent social relations) are just one of the many sets of elements that construct these spaces. Space and circulations are therefore co-constituted; they connect up with one another through complex relational webs, alterations in one set of relations potentially affecting the structure of others.

In addition to highlighting the social production of space, network approaches have had value for helping the security literature to overcome 'the tyranny of distance' (Murdoch, 1998). Rather that space being absolute, network approaches have allowed security scholars to think in terms of relational space (the space of relations). Here, the traditional dualisms that have plagued spatial imaginations in the past are overcome (Murdoch, 1998) – the local is simultaneously global, society and nature are complexly intertwined rather than abstractly separated, and the micro is potentially equal to the macro (Latour, 1993; Law, 2007). In this relational space, two actors that were previously separated by extreme distance can be very close. Through their relational connectedness, an event on one side of the world may be generative of insecurities for a nation/city/individual/object on the other. In this manner, network approaches enable researchers to better appreciate the ways in which elements previously considered disconnected due to their physical distance, can become intricately involved in the construction of other faraway spaces, and may be productive of forms of (in)security within these distant contexts.

Perhaps most significantly however, network-based approaches have emphasised the inherent precariousness of the networks that construct infrastructures and social worlds. Rather than these networks existing independently of their spatial contexts, they require the continued practice of particular sets of social relationships. Infrastructures and social spaces are thus never static, fixed, or finalized, but are dynamic and perpetually open to alteration, change, destabilization, and potentially collapse. They are thus enacted, or performed, and emerge out of the practices of multiple heterogeneous elements. As a result, security appears in these accounts as both an outcome and a project. It is the product of a series of relational performances; an outcome of particular configurations of contingent social relations that must be maintained in order for certain societal functions to persist, but at the same time it is also a project of organizing elements and maintaining sets of relations in order to ensure that particular outcomes continue to be produced.

In these different ways therefore, the concept of the network has had multiple benefits for understanding security's geographical dimensions, the ways in which security is integrated into the fabrics of social life, and the manner in which security is cooperatively practiced. Yet despite these benefits, it is important to reflect upon how network-influenced approaches have also limited the spatialities of security under analysis. Network metaphors encourage us to destabilize the tyranny of distance in absolute space, but this emphasis on relationality also invites security's abstraction in ways that tend to erase the frictions, distances, and circulatory complications that emerge across the extent of entities' physical journeys. This is not to suggest that there is a fundamental problem with network-based approaches to security (indeed, frictions, distances, and interruptions are by no means incompatible with these approaches, for they are also relationally produced), but is more of an issue with the ways in which they have been employed by security scholars.

Visual representations of networks almost invariably depict straight, featureless, lines connected by spherical nodes, whereby these lines (or circulatory trajectories) typically only imply a relationship/connection between nodes. Physical distance, friction and other circulatory qualities are rarely accurately depicted (if at all), and the nodes instead take primary importance. Such representations lend themselves particularly well to circulatory infrastructures (see, for example, tube and flight maps)[17], and linear depictions of circulatory trajectories have consequently become common in portrayals of all kinds of globalised networks (Shields, 1997)[18]. As such, despite the prominence of lines depicting circulations in these representations, the ways in which they are simplified and abstracted has led to analytical emphasis being placed upon the locations where "resources are concentrated": on "the knots and the nodes" where multiple entities "are connected with one another" (Latour, 1987: 180).

The consequence of this is that the security practices that surround telephone wires, data cables, utility pipes, roads, railways, shipping channels, flight paths, and the various other kinds of circulatory infrastructure in-between nodes have received relatively limited attention in the critical security studies literature, whilst the assemblages and security practices that take place within and around these nodes have taken primary position. Indeed, the critical security literature is teeming with accounts of security's practice within a wide variety of nodal spaces, including (but not limited to); airports (Martin, 2010; Adey, 2004; 2009; Salter, 2008; Bennett, 2008; Amoore and Hall, 2009); maritime ports (Cowen, 2010, 2009; Peterson, Joann and Treat, 2008); sites of overland border

[17] Latour (1987) himself uses the example of a telephone infrastructure to explain the constitution of actor-networks, describing how "[t]elephone lines, for instance, are minute and fragile, so minute that they are invisible on a map and so fragile that each may be easily cut; nevertheless, the telephone network 'covers' the whole world" (p.180).

[18] As Shields (1997; 1) notes, "whether on the ground, in the air, or in space, our world is increasingly portrayed not as a solitary blue planet, seen from space, but as a map or disc on a video screen, criss-crossed with animated lines representing a world of people, goods and capital, all in flight".

crossing (Coleman, 2005; Ackleson, 2005; Rossmo, Thurman, Jamieson and Egan, 2008); control rooms (Adey and Anderson, 2011b; Anderson and Adey, 2012); financial data centres (Goede, 2006), and other critical nodes within these systems (Collier and Lakoff, 2008; Aradau, 2010). Even at smaller scales, descriptions of security have tended to focus upon nodes such as cashpoints (Amoore and De Goede, 2005) and supermarket checkouts (Dillon and Lobo-Guerrero, 2008).

Such problems are not just limited to the critical security literature, however. Also relevant to this study is the field of energy security - a body of work that shares many topical similarities with critical security studies, but which has developed largely in isolation from it. Like critical security studies, this security research similarly suffers from dominant narratives of security remaining focused on nodes, but here the 'nodes' take the form of the national scale nodes of production and consumption, with security being framed in terms of the potential consequences of energy interruptions for the maintenance of national and economic security within these nodes (c.f. Bielecki, 2002; Bradshaw, 2009; Yergin, 2006; Wicks MP, 2009; Cornell, 2009; Garibaldi, 2008; Bilgin, 2009; Amineh, 2003; Correljé & van der Linde, 2006).

When framed in terms of nodes of consumption, energy security is typically regarded as the *security of supply* (this is the dominant security narrative in this literature – see, for example; Bohi & Toman, 1996; Drexel, 2009; European Commission, cited in Ölz et al. 2007; Sovacool, 2011b; Yergin, 2006; Wu et al. 2012; Toft et al. 2010), and when it is located in nodes of production, it is typically framed in terms of the *security of demand* (c.f. Birol, 2006; Bradshaw, 2009; Bridge, 2014; Cherp et al. 2012; El Badri, 2008; Lajous, 2004; TNK-BP, 2006; Yergin, 2006; Johansson, 2013; Hoogeveen & Perlot, 2007). Yet both of these narratives portray security as being "lodged in the larger relations among nations and how they interact with one another" (Yergin 2006; 69), and like with the displacement of circulations in critical security studies, here security is reduced to simply the transactional outcome of economic and political arrangements between two or more nodal points, the specificities of the energy's journeys and the way that security becomes manifested along the way being largely overlooked. As a consequence, whilst considerable effort goes into developing, maintaining, regulating and managing the global circulation of energy products, this work is notably absent in academic analyses of energy security. Indeed, as Marriott and Minio-Paluello (2014) have recently complained, "the mobility systems of fuel itself […] remain largely invisible. The institutions, practices and processes that create and enforce [these systems] are rarely examined holistically" (p. 99). As such, energy security's everyday performances are strangely lost in this field, as are the sources of insecurity, friction and disruption that necessitate them[19].

Whilst I highlight the reductive tendencies of both of these literatures here, I do not mean to suggest that there is a complete absence of research that attends to the governance of circulations between nodes. Indeed, within critical security studies, Amoore (2006) and Vaughan-Williams (2010) have offered particularly exciting invitations to extend accounts of security's practice beyond the traditional nodal sites of physical state borders, describing some of the work that is done to "divide bodies at international boundaries, airports, railway stations, on subways or city streets, in the office or the neighborhood" (Amoore, 2006; 338). Despite this call however, there remains a shortage of

[19] There has been work on energy security that has employed other spatial scales, yet there still remains an absence of accounts that attend to the specifics of energy's journeys. This broader work includes those studies that have expanded energy security's definition to include considerations of energy's availability, accessibility, affordability, and acceptability in relation to global, national, regional, local and individual scales (c.f. APERC, 2007; Von Hippel et al., 2011; del Rio & Burguillo, 2008; Tilman et al., 2009; Turton & Barreto, 2006; Vivoda, 2010; Bollen et al. 2010; McCollum et al., 2013; Jacobson, 2009; Mitchell et al. 2013; Pachauri and Spreng, 2004; Parajuli, 2011; Malla, 2013; Priemus and Visser, 1995; Sovacool, 2011a; Reddy & Srinivas, 2009; Wang et al. 2015; Kowsari & Zerriffi, 2011).

detailed empirical accounts of the ways that security is practiced around bodies, materials and things *whilst they are in motion*. In a similar way, Cowen's (2009; 2010) work hints at a progression beyond nodal thinking, as she describes how attempts are made across supply chains to reduce the sources of friction and interruption that emerge around the maritime transport of goods. Yet ultimately, her analytical focus remains on the nodal spaces of maritime ports, her analyses describing the way that securing work is projected out beyond national borders to the nodal spaces of other maritime ports.

Similarly, in the energy security literature there have also been attempts to study the security issues that can emerge across energy's journeys. Nincic (2009, 2010) and Liss (2011) have examined attempts to counter maritime threats to the continued circulation of shipped energy products (pirates, geopolitical frictions over arctic sea routes, terrorist attacks, military interventions), and a sizable literature has also developed around the topic of critical infrastructure protection (c.f. Koknar, 2009; Amin, 2005; Jaradat & Keating, 2014; Rudner, 2008; Farrell et al. 2004). Whilst these scholars engage with security at the level of energy's circulatory infrastructures however, focus remains firmly placed upon critical nodes and choke points, rather than on the broader everyday performances of security conducted across these systems.

As a result, whilst the current approaches employed in the security literature have been undeniably productive for understanding contemporary practices of security (and I certainly do not wish to suggest that nodes, or 'moorings', are not important), it is my contention that these studies have frequently come at the expense of analyses of the (in)securities that may develop across the journeys of circulating entities. This is a matter that clearly merits greater academic attention. Indeed, this is one of the central objectives of my thesis: to follow the journeys of one particular circulatory thing (here, natural gas) beyond the centralised points through which it passes, closely documenting the ways in which specific insecurities and security practices develop, as these gaseous molecules travel.

A number of studies from outside the specific fields of security research may help us to do this. In terms of more general practices of circulatory governance, valuable work has developed around the close management of food circulations (Nimmo, 2011; Twilley, 2014; Dunn, 2011; Atkins, 2004, 2011, 2010), the interruptions, discontinuities, frictions and seams in global cargo flows (Gregson et al., 2016), much of the work on mobilities (c.f. Cidell, 2012; Peters, 2014; Peters & Turner, 2015; Cresswell, 2010; 2014; Merriman, 2015), and the safe and efficient global transport of different energy products (Mitchell, 2009; 2013; Barry, 2013). Indeed, these latter two authors have been particularly influential to this thesis: Mitchell (2009; 2013) has analysed the political potentialities and governing practices that surround the movements of various kinds of energy product, and Barry (2013) has explored the regulation of information relating to the circulation of oil and the forms of politics that subsequently emerge as it flows within pipelines. Like myself, these authors are similarly concerned with the governance practices that are employed along the extent of energy's journeys between nodes, and both document the emergence of particular kinds of politics along these travels. Neither, however, explores such practices through a security lens.

III. Logics

In addition to undergoing an expansion in the spatial scales at which circulation has been explored, the critical security literature has also undergone significant developments with regards to the way that security's guiding logics have been conceptualised. As Peoples & Vaughan-Williams (2010) acknowledge, one of the unifying threads that runs through the critical security literature is a shared interest in what security means, what logics drive its practice, and who and what its referent objects are. Many definitions of security have been produced within this work, and security has consequently been described as an "essentially contested concept" (Baldwin, 1997: 10, cited in Peoples & Vaughan-Williams 2010).

One of the most influential definitions relates to the concept of securitization that was produced by the 'Copenhagen School' of scholars during the 1990s[20]. Security is regarded in these accounts as operating according to *a logic of survival*, Buzan, Wæver and De Wilde (1998: 27) broadly defining it as "survival in the face of existential threats". Circulations are considered to be a major source of such threats. The introduction of new elements through circulations can open up a series of possibly destabilizing aleatory scenarios, but the enrolment of these elements within social processes may simultaneously be essential for the continued functioning of liberal life. 'Securitization' refers to the process through which such threats are addressed. It is seen to involve the elevation of particular conditions to a level above that of everyday politics in order to justify the use of exceptional measures in response (Wæver, 1995). Securitization consequently operates along a spectrum of politicization: at one extreme is the banal, every day, and non-politicized, and at the other is that which presents existential threats and must therefore be securitized (Buzan et al. 1998). As such, security is seen to function specifically in the domain of exceptional politics, conditions only becoming matters of security when they exit the field of public political debate. The definition of security employed in this work is therefore founded upon a principle of exceptionalism: it is about making a distinction between that which is considered to constitute the everyday, safe, and routine, and that which is to be considered deviant, threatening and alien. Moreover, it is about claiming the authority to

[20] See, for reference, the work of Barry Buzan, Ole Wæver and Jaap de Wilde.

indisputably prescribe the mode of response to these threats, and for this mode of response to exceed the boundaries of normal lawful conduct.

As Ole Wæver (1995) has argued, the elevation of conditions to the level of the exceptional is typically achieved through the conduct of 'speech acts'; discursive practices through which an actor "claims a special right to use whatever means are necessary to block [particular existential threats]" (p.35). Yet for securitization scholars, the actual existence of such threats is not as important as the act of declaring something a matter of security (Buzan, Wæver and De Wilde, 1998). Indeed, the perception and definition of threats is subjective, and may be open for political exploitation (Ibid). What they claim *is* important however, is how particular speech acts are made, how they develop traction, and what forms of exceptional measure and political formation may become legitimized as a result.

There is therefore substantial overlap between the Copenhagen School conceptualization of security and those found in more traditional security studies texts. Existential threats may be framed in terms of military or terrorist forces that endanger the survival of the nation state, and these threats may be seen to justify the use of exceptional measures (such as heightened surveillance and indefinite detention). Yet this work has also lent itself to broader analyses that take alternative referent objects as their focus. Securitization scholars have been concerned with the survival of entities from numerous spheres, including; environments and the flora, fauna and human inhabitants that may live within them; economics, including the economic survival of national economies, large businesses and financial institutions; politics, including the survival of international institutions such as the EU, individual states and local political units; and social structures such as community identities and collective livelihoods[21].

Furthermore, in expanding the referent objects under study, the securitization literature has also remained open to a much broader range of sources of insecurity than traditional security accounts. In principle, *any* phenomena can be considered a security issue, provided that it is seen to present threats to the continued existence of a referent object, and provided that these threats are considered to necessitate the adoption of exceptional political measures.

Moreover, the securitization literature has expanded the range of actors considered to potentially be involved in security's practice. As Wæver (1995) notes, securitizing speech acts do not have to be articulated only by state representatives, but can instead be performed by specific human actors that have sufficient social and political capital to convince others of the existence and severity of particular threats (even then however, attempts at securitization may not be successful due to other contextual factors[22]).

It is this kind of survivalist logic that underpins the majority of accounts of energy security. Turbulence or uncertainty in the continued circulation of energy products is presented as potentially threatening to the continued existences of nations that rely on its sale or consumption, and as a result, attempts are made to securitize energy in ways that legitimise particular

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[21] See Buzan, Wæver and De Wilde (1998) for a detailed overview of these different empirical focuses.

[22] Such contextual factors may include the context in which the speech act is made (including its location and timing), the content of the speech act and its connections to historical discourses, and the adherence of the speaker to social/political/economic conventions (Wæver, 1995). Ultimately, in order for a matter to become securitized, a speech act must be accepted by its audience (Peoples and Vaughan-Williams, 2010). For a discussion on similar ideas in relation to the stability of financial systems, see the work on financial performativity - a summary of which is provided by Morris (2016).

exceptional forms of intervention, such as state intervention in liberalised energy markets (Bridge, 2014).

Despite the influence of these securitization approaches and the ways in which they have expanded upon traditionalist accounts however, the emphasis these authors place upon exceptionalist speech acts as conducted by influential elites has not been universally accepted in the critical security studies literature. Indeed, one particularly significant point of contention has concerned how such approaches have mobilised a definition of security that discretely situates it within the sphere of exceptionalist politics. As Rita Abrahamsen (2005) explains;

"The insistence on defining security as 'existential threat' and the sharp distinction between normal, everyday politics and 'emergency action' means that many of the processes and modalities whereby issues come to be feared and experienced as potentially dangerous cannot be adequately captured within this perspective. In most cases, this is a very gradual process and only very rarely does an issue move directly from normalcy to urgency. Rather than emergency action, most security politics is concerned with the much more mundane management of risk, and security issues can be seen to move on a continuum from normalcy to worrisome/troublesome to risk and to existential threat – and conversely, from threat to risk and back to normalcy. The process of securitization is thus better understood as gradual and incremental, and importantly, an issue can be placed on the security continuum without necessarily ever reaching the category of existential threat" (p. 59).

In Abrahamsen's approach, security continues to be viewed in terms of a logic of survival, but she also introduces two significant consequences. The first is that the issues, threats and conditions that fall under the scope of securitization practices must be expanded. Rather than phenomena becoming security matters only through the suspension of normal political conduct, any issue that is considered to have the potential to escalate to the point at which it presents existential risks may become the focus of securitization attempts. Due to their potential to produce various forms of societal instability, many of the circulations that saturate, and that are productive of, day to day social existence may therefore become the focus of securitization. As such, securitization and politicization cannot be cleanly separated into two discrete outcomes (Acharya, 2006): security performances permeate every day, 'normal' and non-political scenarios, shifting, adapting, scaling up and receding, all in response to the contingent behaviour of the circulations in focus.

Moreover, Abrahamsen's critique also has a second corollary, for it necessitates the broadening of the kinds of security practice that are included within analyses of security. Whilst advocates of the Copenhagen School approach would consider any securitizing speech act that does not result in the acceptance of political norms being suspended as being a failed attempt at securitization, this expanded approach accommodates a multiplicity of security utterances that are issued by a broad range of actors (Abrahamsen, 2005). As such, this approach focuses much more closely on the diffuse construction of discourse. Instead of placing exclusive priority upon singular influential speech acts, it explores the broad formation of discourses of security and interrogates the consequences that these discourses may have for the way that people, spaces and things come to be governed.

Yet despite Abrahamsen's approach showing a recognition of some of the ways in which security practices may become folded into the politics of the everyday, she continues to make significant exclusions regarding what can or cannot be regarded as a security issue, what is or is not a securitizing practice, and who or what might be considered to be involved in security's conduct. Such exclusions ultimately derive from her analytic restriction of security practices to discursive acts, and from her adoption of a definition of discourse that principally associates it with the deployment of language. According to this definition, discourse is semantic associations that condition the forms of action that are possible within a given moment and which prescribe the kinds of political future that can consequently unfold, and as a result, security is reduced to a set of practices that relate to words and their utterance, whilst the actors involved in its performance are also limited to those who have the ability to speak.

Broadly building upon the Foucault-inspired work of the Paris School (c.f. Bigo, 2001; Amoore, 2006; De Goede, 2007; Salter, 2008), a body of literature has recently emerged that provides an alternative to such linguistic restrictions. This work has been developed by a range of authors from political geography, political science, and international relations, and offers a conceptualization of security that rejects the focus on exceptionalism advocated by the Copenhagen School, while at the same time greatly expanding the criteria for what qualifies as a security actor and a security practice.

Indeed, if the work on securitization through speech acts is considered to have its foundations in a linguistic definition of discourse, this more recent body of work can be thought of as framed around a materialist definition of discourse[23]. Here, discourse remains that which enables and constrains what can be said, known, or enacted, but instead of being constituted only through verbal utterances, it forms through the specific arrangements of relations between human, material, and immaterial actors within particular spatio-historical contexts. Security thus remains a set of discursive practices, but here the discourses feature as complex socio-material networks. Security accordingly consists of a diffuse set of practices that are performed by complex and constantly shifting associations between heterogeneous actors (Huysmans,

[23] See Barad (2007) for an excellent outline of how materialized discourses may be conceptualised.

2011), and these practices involve the rearranging of socio-material relations in ways that make possible or constrain the emergence of particular eventful phenomena. As such, circulations might be understood to be organised through meticulous practices of relational manipulation[24].

An example of such a socio-material network is described by Huysmans (2011, citing Neyland 2009). He describes the careful construction of a system of words, bodies and practices around the circulation of mail in the attempt to 'cancel out' the threat of letter bombs. Here, a speech act that is constructed through a MI5 webpage that advises members of the public about how to identify possible letter bombs, forms only one part of "a whole set of banal, little connections (e.g. postal delivery, postal sorting, explosive or incendiary substances, posting, unusual place of origin, couriers, recipients, the place of origin of the sender, police)" (p. 376). These connections are carefully structured to constrain what phenomena are possible within a given moment; like linguistic discursive arrangements they similarly enable and constrain what can be said, known, or enacted, but they are instead constructed through the relationships between people, bodies, words and things.

Whilst socio-material accounts of security consequently appreciate the role of speech in security performances, they also expand significantly beyond these acts (grand or otherwise), drawing attention to how they are mediated by the practices of diverse entities and materials such as websites, newspapers and signs. Moreover, they can also go entirely beyond the formation of linguistic acts to explore distinctly non-verbal security practices, with studies describing in detail how a wide variety of human and non-human actors (including CCTV cameras, physical barriers to access, identity cards, passports, border guards, and algorithms) come together at different times and in different places to

[24] Often however, these accounts still lean towards descriptions of security that distills it into practices of circulatory filtration and maintenance.

collectively identify particular kinds of threat and opportunity, and respond to them.

Yet whilst such studies share in common a conceptualization of security as diffuse and distributed, there are some significant variations in the ways in which security actors and security practices are defined in this work. One of the most common perspectives, as seen in the work of scholars such as Amoore and de Goede (2008), Huysmans (2011), and Vaughan-Williams (2010) involves the definition of security actors through their participation in practices of drawing lines between acceptable and exceptional subjects. Although rarely explicitly outlined in this work, security typically operates in these accounts according to a logic of *the continuation, or persistence* of, particular identifiable qualities of the referent objects that are in need of protection, rather than change and transformation being completely avoided, as implied by survivalist logics. Phenomena that may potentially threaten these qualities are identified and isolated through the actions of diverse, contingent and constantly changing networks of human and non-human actors, and instead of critical moments whereby exceptions are decisively defined, security performances are envisioned as "a myriad of decisions in a process that is continuously made and remade" (Huysmans, 2011: 376). Such decisions are diffuse, rarely coherently organised, and do not necessarily have to entail the suspension of normal modes of political practice. Any action or form of decision that contributes to the outcomes of threat delineation and isolation is regarded as a security practice, and security actors are defined through their participation in these practices. As such, a security actor can be any human or non-human entity that is involved in the distributed process of producing decisions, regardless of whether it has the capacity to 'speak', let alone to speak with authority.

In this way, circulations are divided into flows of safe and risky entities, a heterogeneous collection of actors working together to define and isolate those forms of circulation that present threats. Such circulations are also managed according to their risks of interruption. Attempts are made to identify and apprehend the forms of contingent phenomena (such as sources of rupture and friction) that could produce insecurities through their interaction with essential circulations. Indeed, this highlights a failing in this work that I hope to begin to address in this thesis; namely that security's practice tends to be reduced in these accounts to practices of circulatory maintenance or circulatory filtration.

Moreover, as a number of scholars have noted (c.f. Amoore and de Goede, 2008; Huysmans, 2011; Ciuta, 2010), the extension of the responsibility for security to human and nonhuman actors makes the practical matter of identifying a security actor and a securing action very difficult to definitively achieve. Decisions are made possible, and emerge out of, the multiple actions of a dispersed array of bodies, objects and things that at any one moment are folded into, and are constitutive of, everyday realities. As Huysmans (2011; 377) writes, "[m]any little and banal daily activities, meetings, and regulations are actively part of the shaping of securitizing practices", and these connections therefore "challenge the boundary between security practice and everyday life"[25]. Furthermore, even practices, devices and technologies that may seem exceptional can become normalized and routine, making distinction between that which composes the everyday and that which constitutes a security performance an almost impossible task[26]. It is also very hard to

[25] It is worthwhile noting that Huysmans (2011) uses the term 'little security nothings' to describe these 'infinitesimal mediations' (p. 379). This term is avoided in this account because it is deemed to be both inadequate and misleading due to the way that it discursively dematerializes security practices and potentially reduces their significance.
[26] Goold, Loader and Thumala (2013) provide a good example of this in their discussion of the way that CCTV cameras and public surveillance has become normalized over time. Many other contemporary examples exist however, including the deployment of risk algorithms within the

ascertain what actually defines a decision, due to how the diffused nature of these performances may cause individual actors to be unaware that they are making decisions in their everyday lives, and to be unaware of the cumulative significance of their decisions.

Arguably, these issues could severely reduce the analytical value of security as a concept. Every action that is performed by any element could consequently be interpreted through a security lens, with the risk of security consequently becoming a totalizing concept (Ciuta, 2010). Moreover, the diffusion of causality in these perspectives also potentially undermines the accountability of specific actors for the emergence of securing practices, and for the forms of exceptional politics that come to be employed (Huysmans, 2011).

Yet whilst these concerns are certainly not unfounded, I maintain that they are insufficient to warrant the jettison of security as a concept, and definitely do not require the abandonment of these diffuse perspectives. Security cannot be adequately understood without attending to practices that exceed exceptionalist speech acts: it often takes forms that are hidden from view and might not require public acceptance (see, for example, the continuation of contemporary practices of mass surveillance), its practices frequently become normalised and fades into the background of everyday life (consider, for example, CCTV practices), or it may involve a series of seemingly low-key practices that place a situation on a spectrum of securitization (Abrahamsen, 2005), whereby such situations can scale up, or scale down in political priority. Such approaches may extend security to every extremity of social existence, but whilst it might not always be possible to exhaustively identify all of the elements and connections that contribute to the formation of these outcomes, it is still possible (and indeed, important) to try to identify how certain

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sphere of public commerce and the widespread public adoption of military-developed global positioning technology through the use of satnavs and smartphones.

securitization practices emerge and attempt to determine their consequences for the structuring of social life – even if we must ultimately recognize that any findings developed will necessarily always be incomplete and partial. As such, whilst security practices can proliferate under these approaches, security as a terms is not emptied of its meaning (Ciuta, 2010).

In addition to these post-structuralist based approaches that focus on the definition of exceptions, a second related, but distinct, body of thought has developed out of close readings of Foucault's (2007) lectures on biopolitical security apparatuses. This work diverges from approaches founded upon the distinction of exceptional subjects (which likewise have tended to draw heavily on aspects of Foucault's work) in that these authors define security through a logic of *social productivity*, rather than the survival or continuation of referent objects. In this work, security actors and practices are similarly identified through their roles in diffuse security performances, but these performances are centred around the task of enhancing social effects instead of simply demarcating unacceptable phenomenal subjects.

For Foucault, biopolitics is a form of security practice[27] in which species life is taken as security's referent object. It involves the regulation of bodies at the level of populations, and instead of limiting security to a strategy of identifying, apprehending, vilifying, and eliminating rogue elements within these populations, it concerns itself with the science of making 'life live' (Dillon and Lobo-Guerrero, 2008; 269). The central project of biopolitical security assemblages is therefore to maximize the productivity of populations whilst simultaneously minimizing the influence of threatening elements. Circulations are "the space of operation in biopolitics" (Ibid; 268), and it is through their management that this productivity is increased. This may entail restricting flows

[27] Dillon and Lobo-Guerrero (2008; 266) state; "there is no biopolitics which is not simultaneously also a security apparatus".

of undesirable entities, but it can also involve maintaining circulations and altering their characteristics (volume, quality, timeliness, and so on) in order to optimize the conditions for human life. As such, security is "not a politics of identity – enacting a self-other dialectic through discursive practices of identity production. It is a complex array of changing mechanisms concerned with regulating the contingent economy of species life" (Ibid; 268).

In agreement with the 'security as continuation' approaches described above, biopolitical security perspectives maintain that security is performed by a multiplicity of heterogeneous actors that permeate and infuse everyday life. Yet in contrast, the definition of what constitutes a securing actor and a security practice is significantly broadened. Security is still considered to incorporate moves to defend particular referent objects (in this case, productive populations), but "it is their very fructification that is being sought, not their simple protection" (Dillon and Lobo-Guerrero 2008; 271). Security is about arranging, organizing, and regulating human bodies, their socio-material milieus, and the forceful relationships that exist between these elements in order to optimize the productivity of a wider population. Put in terms of discourse, it involves arranging particular discursive apparatuses in order to enhance social productivity. As such, security performances may similarly include practices through which exceptional subjects are delineated, but they also exceed these practices to cover the active transformation of security's subjects in the pursuit of popular productivity.

In broadening the kinds of actors and practices involved in security performances in this way, significant challenges are raised for effectively discriminating between those practices that relate to security, and those that constitute more generalized actions of governance. Security in this work often features as incredibly mundane sets of routines and behaviours, such as the profiling of consumers through supermarket 'Nectar' cards (Dillon and Lobo-Guerrero, 2008), and as a result, the line between what distinguishes a security practice and a practice of governance is increasingly blurred. Ultimately what must separate these actions are the logics that guide them and the referent objects that they attend to. A security practice in this literature is therefore defined as any practice that, regardless of an actors' intent, forms part of a wider project of enhancing the productivity of a wider population.

When held in relief (exceptionalist accounts of security and biopolitical accounts) there appears to be a trade-off. Whilst the literature on diffuse security performances of exceptional subjects rarely explicitly isolates its analysis to singular referent objects (and it therefore remains open to security analyses that examine the full diversity of elements described earlier in this chapter - including environments, religions, political structures, economic units, and social groups), the work on diffused biopolitical performances of security restricts itself to the single referent object of species life. At the same time however, the literature on exceptionalist security performances also commits itself to a limited definition of security in which continuation and protection determine the actions and actors that are associated with security's performance. Here security is about identification, isolation, restriction, and containment, whereas the biopolitical security literature remains open to security actions that are not simply protective, but are also productively transformative. Security in biopolitical accounts is therefore more broadly concerned with management and regulation (although identification, isolation, restriction and containment may all feature in these practices).

In the case of gas, it is apparent that there are potentially multiple referent objects of security at play (nations, governments, economies, corporations, individuals, populations, environments), and that security is not simply a restrictive practice, but a productive one. The question presented by this work is therefore whether it is possible to combine the best of these two materialist security approaches – a biopolitical security approach, and an exceptionalist approach – in a meaningful way in order to analyse security's performance in relation to energy's circulation, and the plethora of interests that become involved with it throughout its travels.

My answer to this question is 'yes'. Biopolitical accounts of security do not prohibit the analysis of security's performance of the exception, for in these accounts the delineation of subjects is just one part of a larger project of optimizing social production. But whilst biopolitical accounts do take species life as their exclusive referent object, they also explicitly acknowledge that biopolitical security practices have formed out of, and are situated within, a particular socio-historical context. As a result, they constitute only one of potentially multiple kinds of security practice. Other manifestations of security may exist, and whilst these can operate according to similar productive logics, they could also take alternative referent objects as their points of reference.

In this thesis, I therefore look to explore security's performance on this basis. Security from this position involves the re-ordering of socio-material discursive apparatuses in order to alter the conditions that determine the forms of perception, speech, and action that can emerge in a given moment. These practices do not have to be restrictive. They can operate according to a logic that seeks to enforce certain forms of relational stasis, but they may also be productive, focused around enhancing productivity and creating new forms of relational architecture and social condition. Crucially however, the security actors involved in these alterations do not have to be united under a common logic (such as, for example, enhancing the productivity of species life). Whilst they may all simultaneously act upon the same elements in various ways, the referent objects that they seek to protect/prolong/improve may all be different, with security actors making alterations to socio-material apparatuses according to their different interests.

As a consequence of this position, this thesis must inhabit a zone of indistinction. It must begin from the starting point that it is not always possible to determine what is and what is not a security practice, as opposed to a normal function of governance. Despite this however, it 'stays with the trouble' (Haraway, 2010, 2016), and attempts to explore how 'secure' subjects are performed through the diffuse practices of heterogeneous elements, documenting the way that these practices shift, adapt, scale up, and recede, all in accordance with the contingent behaviour of the circulatory phenomena in focus.

IV. Materials

Finally, in addition to the limitations described in the previous two sections, the security literature is also limited in the way that it has portrayed the roles of materials in security performances. Indeed, this is critical for the main argument of this thesis, for in order to better understand security, I argue that we have to attend to the specific materialities of the circulating elements in focus.

Broadly speaking, there have been two main approaches to materials in this work. On the one hand, a large literature limits security to human actors that are capable of speech, and on the other a burgeoning literature regards materials as active participants in the production of security's subjects.

This second literature has been strongly influenced by the post-structuralist network-based theoretical perspectives described previously, and through these approaches, the need to treat humans and nonhumans on equal terms has been extensively emphasized. Both nonhumans and humans are regarded as having the same potential to act (Law, 2007; Latour 1993), and power is seen to circulate between these entities through complex webs of social relations. It is from the arrangement of these relations that relational power architectures are constructed, and that security's emergent subjects are produced.

Understanding security to operate through such diffuse webs of relations has helped researchers to break down the faceless mass of 'the nation state' into a multiplicity of 'petty sovereigns'[28] that collectively enact state decisions. Such petty sovereigns have been shown to include (amongst other actors); politicians (Heath-Kelly, 2015), border guards (Amoore, 2011, 2007), CCTV analysts (Adey, 2004; Salter, 2008), the designers of risk algorithms (Amoore, 2011), and even academics who may unintentionally reproduce security discourses through their writing (Eriksson, 1999). Moreover, these approaches have also extended the scope of security research to examine various kinds of non-state actors that may become involved in security performances, including private companies (Petersen, 2008; Aitken, 2011; Walker and Cooper, 2011; Sparke, 2006) and members of the public (Amoore, 2006; Closs Stephens, 2007). Perhaps most radically however, they have also thrown light upon the role of material actors within performances of security. Broadly speaking, there are four ways in which materials have featured in this work: as material architectures, as decision makers, as obstacles, and as travellers.

The first of these, *material architectures*, refers to the way that materials have effects on circulating bodies/things and can constrain/facilitate their abilities to act in different contexts. The quintessential security architecture described in

[28] See (Butler, 2004) 'Precarious Life' p. 66 for a description of 'petty sovereigns'. Whilst Butler frames petty sovereigns as principally consisting of human actors, the concept of the petty sovereign – of a decentralized actor that articulates sovereign power – has been expanded to also incorporate different kinds of materials in other scholars' accounts.

this literature is the airport. The materials that construct and constitute these spaces are arranged in specific ways to "control and direct the masses of passengers" moving between destinations (Pascoe, 2001; 226), and materials are distributed to enable the more or less frictionless movement of these bodies (Salter, 2008), with wide corridors, escalators, moving walkways, large directional signs on floors and above heads, and a wide variety of fences, doors and barriers all efficiently channelling flows of human bodies in different directions. Space is not passive here. The materials that constitute space are actively enrolled in security's performance; they enable bodies to move smoothly, and they thereby maintain the uninterrupted circulation of people. Yet they also simultaneously constrain these bodies. Materials such as CCTV cameras, x-ray scanners, metal detectors, guard uniforms, weapons and barriers combine with other discursive elements to produce affective atmospheres of security. Such atmospheres may have disciplining affects, enabling the production of mollified and confessing security subjects (Salter, 2007), but they may also express themselves in other ways, such as in boredom and excitement (Anderson, 2015)[29].

The second material form of this literature, *materialized decision makers*, refers to the way that heterogeneous collectives are productive of the decisions over which circulating bodies and things are considered to be safe (and should therefore be permitted to travel onward), and those that are exceptional (and therefore require arrest). This literature has shown human acts of decision to only be made possible through the cooperation of distributed materials, which have included such seemingly mundane objects as the RFID passports that help to identify and track passengers (Salter, 2003; Torpey, 2000; Walters and

[29] Other architectures have also been shown to produce different forms of securitized subject. For example, Vaughan-Williams (2015) has described how migrants are dehumanized/animalized through the 'zoo-like' physical conditions that are forced upon them within the European border security and detention systems, and Cowen (2009) has examined how materials within maritime port spaces are organised in ways that minimise the frictional forces operating on cargo circulations.

Vanderlip, 2015), and posters that explain the kinds of incident that members of the public should find suspicious and should consequently report (Closs Stephens, 2007). Radically however, materialist security scholars have also demonstrated that materials may become intimately involved in the drawing of lines of exceptionality. Numerous studies have described how such diverse objects as x-ray machines and body scanners (Amoore and Hall, 2009; Diken and Laustsen, 2006); polygraph devices (Adey, 2004); chemical, biological, radiological, nuclear and explosive device detectors (Bourne, Johnson and Lisle, 2015); gait scanners (Adey, 2004; Cresswell, 2010); cash points (Amoore and de Goede, 2008); and database-connected electronic profiling systems (Lyon, 2007; Norris, 2003; Amoore, 2006, 2016; Amoore and Hall, 2009; Vaughan-Williams, 2010; Amoore and De Goede, 2005; de Goede, 2012) can all assume a pivotal role in the multiple daily processes through which exceptional circulations are defined.

The primary contribution of this literature has been to showcase how the allocation of responsibility in security's performance is troubled by the mediated quality of these decisions. Amoore (2011), for example, has demonstrated how the algorithms through which travellers are flagged as risks, are actually the products of numerous software engineers, politicians and policy makers, and have often been expanded and developed in different security contexts[30]. As such, they may contain remnants of their histories that

[30] The software that is used in the delineation of airport security risks, for instance, may also have been developed for military, insurance, and financial applications (Amoore, 2011). Interestingly, many of these systems also operate on the assumption that human agency can be broken down into the associations they have formed between different heterogeneous elements. For example, algorithmic border security systems such as the NetReveal system developed by Detica draw upon vast quantities of data (including phone records, credit histories, online bookings, travel histories, and even blood donor records and flight meal preferences) in order to build relational profiles of travelers and assess their relative risk (Vaughan-Williams, 2009, 2010). Human agency is seen to be the product of these relations, and lines are consequently drawn between those associations that are considered to be productive of particular forms of threatening agency, and those that are considered to be safe. Sorted identities are then attached to their corresponding bodies through the use of biometric

affect the framing of subsequent decisions. Exactly where the origins of a particular decision are located thus becomes difficult to ascertain.

Moreover, the complexity of such decisions' emergence has been shown to not just enhance the uncertainty with which responsibility can be allocated: it can also endow decisions with an opacity that makes their rigorous scrutiny and interrogation, and the holding to account of individual elements, extremely difficult to achieve. Amoore (2011) provides one example of this, describing how the 'black boxing' of risk profiling systems can make it hard for secured subjects to challenge the way that they are digitally categorized as existential risks. As such, diffuse decisions can effectively stifle opportunities for resistance.

The third material form, *material obstacles*, then involves the destabilizing potential of materials for smooth circulations. Materials may present existential threats through the way that they can interrupt critical circulations, as in the case of the disturbances to air traffic caused by the Icelandic ash cloud in 2010 (Adey and Anderson 2011a), but they may also create certain forms of friction, such as in the tensions created between materialized practices of securitized filtration within airport spaces and the smooth movement of bodies (Adey et al., 2013; Adey, 2004).

Finally, materials have undertaken the role of *travellers* in this literature. Over a decade ago, Adey (2004) lamented the shortage of critical security accounts that attended to such circulations, writing of how there remained a "tendency to limit our understanding of mobilities to humans" (Ibid; 502). Whilst the majority of contemporary studies of security still remain concerned with security's performance in relation to such human circulatory figures as the

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identifiers (iris scans, finger prints, passport photographs), and personal codifiers (such as bank account PIN numbers), thereby enabling the physical division of safe and risky subjects.

terrorist (Heath-Kelly, 2015; Amoore and De Goede, 2005; Aradau and van Munster, 2008; Petersen, 2008); the 'illegal' immigrant (Huysmans, 2000; Doty, 1998; Money, 1999; Walters, 2010; Astor, 2009; Jordan and Brown, 2007) and the asylum seeker (Rajaram, 2008; Gill, 2010; Mountz, 2011; Darling, 2009), a sizable body of work has now also developed around various kinds of material flow. De Goede (2012, 2007, 2006, 2003), for example, has written about the securing of financial circulations; Adey (2004) has discussed the circulation of luggage; Cowen (2010, 2009) and Mutlu (2015) have looked at the circulation of shipping containers; Elbe, Roemer-Mahler and Long (2014), Hinchliffe and Bingham (2008) and Clark (2013) have documented the securing of influenza and other forms of contagion; Ackleson (2005) and Bourne (2015) have described the securing of narcotics; Bingham and Lavau (2012) have examined the securing of moving foodborne pathogens, and Duffield (2001) has looked at the securitization of international aid. This list is not exhaustive, but it is indicative of the broad literature that is now available relating to the performance of security in relation to diverse material travellers.

Yet whilst this literature has opened up to the movements of a wide variety of materials, few studies have closely attended to the way that these materials are contingently performed as secure subjects. This, I suggest, is a result of a tendency of this literature to focus on the apparatuses and practices of security, over the specificities of the entities being secured and the particular transformations that they undergo through security's practice. Indeed, this, as I suggested in the previous chapter, is itself symptomatic of a habit of treating security as a noun (Dillon, 1996); as a thing that can, to some extent, be abstracted from its contextual specificities in ways that enable its deployment in relation to a variety of very different objects. This seems to be the case with the way that security has been seen to operate in relation to circulations. Closely following Foucault's (2007) distinction, circulatory security is typically reduced in this work to two sets of practices: to practices of circulatory filtration, and to practices of circulatory maintenance. Little attention is paid to the way that materials are changed through these practices, nor to how particular phenomena are 'compensated for', 'limited' or 'cancelled out' (Foucault, 2007)[31], and material circulations consequently often appear in this work as if on rails. Work goes into ensuring that they continue to smoothly circulate, or to ensure that they periodically change track/are diverted so as to separate risky entities from safe ones, but across these journeys, matter typically remains unchanged. Objects almost invariably require only periodic filtration and reliable modes of transport in order to be secured.

A result of this is that travelling materials are frequently presented as almost entirely passive or inert. The vibrancy and contingency of objects that is emphasized within the ANT and assemblage literatures is strangely underplayed in relation to the movement of materials (Adey and Anderson, 2012). This is problematic, for it not only overlooks the way that security has to be performed in sites other than points of filtration in order to transform, subdue, or enhance the productivity of particular circulations, but it also fails to acknowledge the potential of these entities to develop unexpected and destabilizing forms of agency. Moreover, it also ignores the ways in which the specific qualities of different entities require very different forms of security practice (often which operate at a relational level) in order for them to be rendered secure.

Indeed, this critique also extends to the materials performing security. Whilst materialist security scholars have been willing to open their analyses up to the participation of materials, relatively little attention has been paid to how these

[31] Foucault does appreciate that materials undergo transformations throughout their travels, but his reflection on these transformations is only very fleeting. Almost no attention is paid to their specifics or to their consequences, and concern is instead principally placed upon the production of human bodies, rather than the subjectification of materials.

performances may be complicated by materials acting in ways other than intended. This is particularly odd given that material failures, unexpected interactions, and autonomous agency are not new concepts in the literature on networked infrastructures (see for example, Graham, 2010b); a body of work that shares considerable thematic overlap with numerous security studies' debates.

Again, this is a set of criticisms that can also be levelled at the energy security literature. The term 'energy' is employed in this work in a classical thermodynamics sense to cover all kinds of energetic material. This terminology, which only began to be employed after many oil-dependent nation-states attempted to diversify their energy mixes following the OPEC oil crisis in the 1970s (Patterson, 2008), works to discursively dematerialise energy products (Bridge, 2014). Provided nation states can acquire sufficient gigawatt hours of energy, the material composition of that energy is of secondary importance. Oil, coal, gas, nuclear and other energy sources consequently became reframed as more or less fungible, and energy itself became increasingly discursively dematerialised. Indeed, as Bridge (2014: 3, citing Hildyard et al. 2012) observes, this is an ongoing process; "wind, water, biomass, fossil fuels are all made equivalent under the banner of 'energy', ignoring the different affordances that each of these distinctive materialisations of energy provides".

Likewise, the vitality of the materials that constitute energy infrastructures has similarly been attended to in a limited capacity. As Haarstad and Wanvik (2016) have noted, there has been a tendency to assume the exaggerated fixity and rigidity of energy infrastructures. Whilst there is undoubtedly value in considering the political implications of such obstinacy and inertia, this heavy emphasis through terms such as energy 'lock-in' (Unruh, 2002), 'carbon democracy' (Mitchell, 2009, 2011b), and 'petro cultures' (Marriott and Minio-Paluello, 2014) has, these authors have argued, worked to obscure instances of change and instability (Haarstad & Wanvik 2016).

As such, we arrive at another of the central claims of this thesis. Far more attention needs to be paid to the vitalism and transformations of circulating entities, the vitalism of the heterogeneous elements that support these circulations, and the ways that these different lively entities affect the security of various referent objects through their clogging up, igniting, breaking, freezing, melting, exploding, decaying, transforming, expanding, or by them expressing themselves through a plethora of other vibrant affects. What we need is a form of entity-attentive security research: one that, whilst holding in focus the configurations of particular security apparatuses, also focuses on the entities that are in circulation, the ways in which the particular qualities of these entities are seen to be productive of particular kinds of future phenomena, the ways in which these qualities necessitate highly specific kinds of securing practice, and the ways in which these entities are transformed through security's practice, in order to facilitate, 'compensate for', 'limit', and 'cancel out' particular kinds of emergent phenomena (Foucault, 2007).

Indeed, beyond the security literature, we again can find numerous accounts that may inform such an entity-attentive agenda. The work on circular economies, for instance (Gregson, Crang, Fuller and Holmes, 2015; Hobson, 2015; Kama, 2015; Gregson and Crang, 2010, 2015a; Gregson, Crang and Antonopoulos, 2016), explores the hard work that goes into transforming materials (particularly waste products) in ways that also transform their economic values. Likewise, relevant research has developed within the field of food geographies, with numerous accounts usefully documenting current and historical developments in practices of circulatory governance, most notably with regards to the management of the decay of different kinds of consumables[32] (Nimmo, 2011; Twilley, 2014; Dunn, 2011; Atkins, 2004, 2011, 2010). Most influentially for this study however, are Mitchell (2009; 2011) and Barry's (2013) accounts of the governance of energy circulations. Mitchell (2009, 2011b) valuably describes the way that the materialities of carbon fuels can be productive of particular forms of (un)democratic politics and can be mobilised for political purposes. Indeed, the materialities of specific resources – principally oil and coal – are shown in this work to condition the forms of politics that have historically emerged. In the case of coal, for instance, its material qualities, when combined with its increasingly widespread consumption, worked to draw the balance of power away from nation states and empower coal workers. This was because coal required large labour forces to excavate, and this facilitated the formation of powerful unions that could challenge state sovereignty through strike action. In contrast however, oil's liquidity and the subterranean pressures that build up behind it are shown to make the possibility of industrial action much harder to achieve, due to it rising to the earth's surface largely of its own accord and consequently requiring much smaller workforces to extract.

Whilst there is much to learn from Mitchell's account in terms of the ways in which the materialities of circulating entities can be politically productive however, Mitchell pays very little attention to the capacities of circulating energy products to transform and mutate during their circulation. Viscous liquid oil invariably remains viscous liquid oil. Solid coal retains its solidity. Energy products rarely stay rigidly and permanently the same throughout their journeys though – indeed, they would be useless if they did, for energy works in its moments of metamorphosis [33]. As such, whilst we need to attend to the

[32] For a fascinating discussion of material decay, see DeSilvey (2006, 2017).

[33] This is actually a benefit of a thermodynamic approach. The transformations undergone by energetic materials and the ways in which energy flows through these different material forms

political futures made possible through these materialities, we also need to attend to how they, and the contingent futures associated with their material expressions, can potentially shift and transform.

Barry (2013) is much more attentive to the capacities of materials to transform. Here, he provides an in-depth account of the ways that oil is ontologically manipulated as it circulates within pipelines in ways that mitigate particular forms of political dispute. Building upon his earlier work on the formation of increasingly 'informed materials' (Barry, 2005), he argues that the governance of information surrounding this energetic material is central to how oil companies attempt to "manag[e] the unruliness of persons and things" (p.4); such companies seeing threats to oil's movement arising from both the material qualities of oil circulations, and from the human actors that are concerned with the development of pipelines. Through regulating the production and distribution of this information, oil companies therefore sought to "govern the[ir] potentially disruptive activity" (p.4). As such, in this 'informed materials' sense, the specific qualities that materials develop across their journeys are shown by Barry to be highly significant for the forms of politics that consequently emerge, and particularly valuably, emphasis is placed upon how the transformation of circulating materials is often a key part of their governance. As such, Barry is much closer to the entity-attentive approach that I seek to advocate, albeit I focus specifically on security, and also place greater empirical emphasis upon the transforming physical qualities of energy as it circulates.

In this thesis, I consequently aim to follow natural gas as it circulates, tracing the processes through which it is rendered secure in multiple ways. In what

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are often politically, socially, economically and environmentally significant - for example, the efficiency of energy's transformations – sunlight to heat, heat to motion, motion to electricity, electricity to light – is a critical factor within contemporary energy systems.

follows, I document the transformations that gas undergoes throughout the duration of its circulations, and attend to not just its own vitality, but also to the vibrancy of the other material actors involved in the ongoing processes of its securing. Particular interest will be placed upon how such materials come to present challenges for security's performance, and how particular strategies are (or perhaps are not) assembled to manage and address these contingencies.

V. Conclusion

In this chapter, I have thus highlighted three areas of controversy that have emerged within the security literature relating to the global circulation of bodies, materials and 'things'. In section II, I attended to the ways that (in)security has been framed geographically. I described the recent shift in security studies away from traditional perspectives that regard security only in terms of the nation state, towards approaches that appreciate a multiplicity of referent objects and possible threats. Building upon this observation, I explained how this shift has led to a significant expansion in the geographical framing of security in critical security studies, with research now including studies of security's performance that extend within and beyond national borders. I also explored the emphasis that has been placed upon global circulations since the 2001 attacks on the World Trade Centre, describing how this has had significant consequences for the way that space has been imagined in relation to (in)security; circulations being seen to extend (in)security into the sphere of the everyday.

This analysis then led me to argue that contemporary security research has tended to overlook performances of security that take place in locations other than the nodal sites through which circulations pass. I claimed that the circulatory journeys of entities through pipes, cables, road infrastructures, airways and shipping lanes, and the various ways in which these entities are secured whilst in transit, have typically received limited attention in this literature. I also drew attention to how similar reductions had taken place in the related, but distinct, field of energy security. Their consequences, I suggested, have been that security research has often failed to recognize the vast amount of securing work that is conducted on a daily basis around these circulations; work that may be critical to the continued stability of various forms of social structure. A central aim of this thesis is therefore to follow gaseous molecules across their circulatory journeys, and to document the forms of security practice that are employed in the process.

In section III, I then examined the competing logics through which security has been seen to operate in this literature. Beginning with the work on securitization theory, I demonstrated how security has been framed according to a logic of *survival*. I showed how this approach remains open to the possibility of multiple referent objects (such as environments, political structures, economic units, and social formations), and described how security has been defined in terms of the continued survival of these objects. Whilst influential, however, I argued that this work limited security's analysis to specific securitizing speech acts through which security threats are defined by their elevation above the level of everyday politics.

I proceeded in this section to contrast the literature on securitization theory against two broadly post-structuralist approaches that have extended security's practice beyond grand speech acts, using these approaches to explore how security is folded into the politics of everyday life. The first – relating to the diffused performance of bordering – was shown to adopt a similar view to the securitization literature, in that it recognizes multiple referent objects and regards security as a project of protection. However, I also showed how this approach is distinct from the securitization literature in that it has defined security through a logic of *continuation*, rather than survival – the difference being that continuation better reflects the potential of referent objects to change during security's performance. Particular qualities and capacities of referent objects are the focus of protection in this approach, protection taking place through the delineation and arrest of potential threats. Crucially, these threats are distinguished through a series of diffuse security practices that are spread out across the social fabrics performing contemporary liberal life, rather than via grand speech acts.

The second approach I described was then the body of work concerned with the biopolitical logic of *social productivity*. Here I showed how, in comparison to other approaches, this work regards security as a productive practice through which the fructification of a referent object is optimized. Yet this approach was also criticised for the way that it limits security to a set of practices that are exercised in relation to a singular referent object: species life. According to this work, multiple diffuse elements were seen to come together to arrange social fabrics in such ways as to maximize the productive output of species populations, limiting its utility for analysing security's conduct in relation to an expanded field of referent objects.

I consequently argued that aspects of both of these literatures have different merits and drawbacks for understanding the ways that gas may come to be secured. Specifically, I highlighted how continuation approaches take a diffuse approach to security that remains open to multiple referent objects, but which limit their analyses to practices through which threats are excluded. I then contrasted this with biopolitical approaches that restrict their analyses to a single referent object, but open their definition of security to include broader productive practices. By then holding these two positions in relief against one another, I suggested that a middle ground, in which security was seen as a set of practices that involves both protection and production, but which also operates upon multiple referent objects, could prove productive for examining contemporary security practices. I thus described a form of security in which the notion of the 'exception' is reframed, and gas shown to become governed in and through its mundane ordinariness, it having securing practices constantly performed around it in ways that facilitate some forms of gaseous phenomena, but that also 'compensate for', 'limit' or 'cancel out' others (Foucault, 2007). As such, I contend that security is not performed exclusively under exceptional circumstances, but takes a more managerial form.

Finally, in section IV of this chapter, I focussed on the role of materials within security performances. I demonstrated how a sizable materialist security literature has now developed, and outlined four of the most prominent roles assumed by materials in this literature. The first of these roles was that of material architectures through which particular kinds of securitized subject are produced. The second was the role of materials in the development of security decisions that define the kinds of circulations that are exceptional (and also the kinds of circulation that are acceptable). The third role then concerned the way that materials present particular forms of obstacles to circulation (either through their interruption of circulations, or through their creation of frictions), and the final role then concerned the way in which materials have featured as travellers, security consequently being seen to operate in relation to these entities.

Developing upon this analysis, I described how this materialist security literature has tended to overlook the vitality of materials within practices of circulatory security. In particular, I drew attention to the way that focus has been placed upon the apparatuses and practices of security, rather than the entities themselves and the transformations they undertake. Circulating materials have consequently often been presented in this work as passive and inert, and security has typically featured as a set of practices that relate to actions of circulatory maintenance and filtration. Again, the consequences of assuming materials to be passive are significant: overlooking the manner in which materials can ignite, explode, decay, bend, break, change direction, have embodied affects and manifold other forms of vital agency throughout the duration of their transit not only ignores a vast range of potential sources of insecurity, but ignores a large amount of securing work that is performed as a result: work that has to take into close consideration the specific qualities of the circulating elements in question.

In drawing these reflections together, I arrive at the two research agendas that underpin this thesis. The first agenda is to challenge the abstraction of security and its associated concepts from the circulating elements around which it is performed. I suggest that security's practice cannot be understood without attending to the ways in which it accommodates, and takes into consideration, the specific qualities of the circulating elements in relation to which it is practiced. In other words, I advocate a form of 'entity-attentive' security research. I pursue this agenda in the chapters that follow, documenting the ways in which gas's specific ontological qualities become folded into security's practice.

My second agenda is then to expand the spaces and scales at which security is analysed. Instead of limiting analyses of security to specific nodal sites through which circulations pass, I suggest that far more attention needs to be paid to the forms of (in)security that develop across the length of elements' journeys. Indeed, I suggest that a vast amount of securing work is conducted around circulations on a daily basis, and that this work cannot simply be reduced to practices of circulatory filtration, or circulatory maintenance. Instead, I advocate a form of security research that conceptualises security as being more managerial, through which attempts are made to regulate the conditions surrounding circulating elements to facilitate, compensate for, or cancel out, particular forms of perceived phenomena.

These two agendas form the basis for the empirical analyses that follow. In the next chapter, I describe the way that they have been incorporated into the methodology of this thesis, and outline the form that fieldwork consequently took.

3

Burrowing

"I'm standing in the middle of what is usually a very busy crossroads that runs by the side of my house. It is currently cordoned off in all directions due to major gas works, and at its centre, a sizable hole has been dug to reveal a large cast iron gas main[34]. One of the engineers from Northern Gas Networks who is working on the site explained to me that this pipe had been classified as being 'at risk', and that these works were part of a larger programme of mains replacement that was being conducted across the country. Despite having spent months researching the UK's natural gas infrastructures, I am still surprised by the scale of this rusting pipe, particularly given that – during the four years that I have lived here – I have been totally unaware of its presence and of the potential threats that it poses.

Extract from field notes: Neville's Cross mains replacement works – 25/8/15 [Site Visit]

I. 'Buried' Associations

Natural gas can be thought of as natural in two senses of the word. First, it forms deep within the ground independently of human action, as opposed to the manufactured gas that was used in the UK before 1970 (this gas was the product of hard labour; workers having to feed iron retorts with coal), and second, natural gas is *naturalized*. Whilst it plays a crucial role in many people's daily lives - we heat our homes with it, cook with it, and use it to warm water for bathing comfortably - most of us never give it much consideration. We come home from work, twist the tap on the hob, give it a press, then click! A spark. An eruption of yellow-blue flame. It is just there, ready and waiting. It provides heat in an instant and is worthy of no further thought.

[34] See 'Image 1' and 'Image 2' in Appendix C.

Yet in other ways, 'natural gas' is also far from natural. Its presence beneath the earth is made knowable through a multitude of technologically complex devices, and it is only via the deployment of a series of established knowledges, bodies and technological instruments, that this gas is securely extracted, processed, pressurized, transported, and consumed. As Bridge (2004; 396) notes "[a] whole industry has emerged […] dedicated to corralling the waywardness and variability of gas and rendering it a commodity compliant with the workings of the market". As such, natural gas is not simply there, ready and waiting, primed to provide heat at the push of a button. Far from it![35] Without complex sets of actors and practices to manage, regulate and secure its transport, natural gas would remain deep beneath our feet, trapped tightly between layers of rock, or it might come to realize a plethora of different forms of potentially hazardous gaseous phenomena. Natural gas, as a known and securely commodified object, requires such complex sets of associations in order for it to exist.

In our day-to-day lives however, we rarely give these associations much thought. The work that has been done to create and regulate natural gas has become buried beneath its "immediate 'thingness'" (Christophers, 2011; 1068), and its "relations [have been] reconfigured so [that] they come to stand, instead, for a reality that by virtue of this process, has become a feature of the natural world" (Law 2010; 6). In other words, the webs of associations that shape natural gas, and which may be strung out widely over space and time, are *translated*; they are made equivalent to the 'thing' in question and are obscured from view; a substitution that can quickly become accepted, or *naturalized* (Callon, 1986a).

[35] An interesting aspect of natural gas is that, unlike electricity, it moves surprisingly slowly. At its fastest, it will reach a speed of 23 miles per hour within pipes. Given the apparent immediacy of its delivery when consumed however, such material qualities often escape the perception of most domestic consumers.

Of significance for this thesis, the 'burying' and erasing from public consciousness of these relations has also been systematically facilitated. Many of gas's movements and associations are *literally buried* in order to hide them from view, and as I shall describe in chapters 6 and 7, this burying constitutes a particular security practice through which gas's circulations are protected from external interference. The ground forms a barrier that both hides the gas from sight and mind, and that also physically obstructs human interactions with it.

As a result of such processes of metaphorically and literally burying gas's relations, many of the actors and practices that are involved in ensuring gas's secure extraction, transport, and consumption have become concealed from everyday view. I have argued in previous chapters that security's practice can only be understood through attending to these associations, and by exploring the way that attempts are made to manipulate them in order to facilitate, compensate for, and 'cancel out' particular forms of gaseous phenomena. As a consequence, and in order to investigate how security is performed in relation to natural gas, this thesis attempts to attend to and describe the constitutive associations through which gas is secured as a particular kind of thing. In doing this, I seek to pursue the two agendas that I have outlined in preceding chapters. I look to explore the way that security is practiced in relation to the specific ontological qualities of the thing in motion (natural gas), and I aim to expand the spaces and scales at which security practices are examined.

To pursue these two aims, I have adopted a methodological approach that is inspired by classic multi-sited ethnographic[36], or 'follow the thing', studies (c.f.

[36] ANT and other 'follow the thing' approaches have often been equated with the method of 'multi-sited ethnography'. This term describes an approach where analysis is conducted at periodic junctures however, and because of this, it does not adequately convey the practice of staying with circulating elements for the duration of their journeys. Whilst it can be employed in this manner, ANT is not restricted to multi-site analysis, and can instead enable us to perform 'continuous' research, whereby relations are traced as they develop across both time and space.

Cook, 2004; Cook and Harrison, 2007; Cook, 2006; Christophers, 2011; Marcus, 1995; Harvey, 1990). Such studies attempt to "get behind the veil" of translation (Harvey, 1990; 423), in order to "map out" (Cook and Harrison, 2007; 40) the constellations of actors that become involved in the shaping of 'things', and to identify "the material circumstances of [their] origination and circulation" (Christophers, 2011; 1068). This typically involves tracing entities backwards[37] through their circulatory routes, identifying the multitudes of heterogeneous actors that form associations with them, and documenting the various ways in which these entities are consequently formed. A follow the thing approach is thus complementary to the two aims of this thesis, enabling me to follow gas as it circulates, and to trace the webs of associations that form around the gas as it travels. Whilst following gas across these journeys, I framed my analysis around three research objectives. These were:

1) ***To identify the heterogeneous actors that become involved in security's performances across gas's circulatory journeys***

2) ***To observe and document the various practices that are employed to render natural gas 'known' and 'secure' throughout the duration of its circulations***

3) ***To document the circumstances and logics under which securing action is considered necessary and is undertaken upon circulations of natural gas***

[37] Sometimes researchers will also follow things forwards. For example, Cook and Harrison (2007) begin their analysis of the networks of production for West Indian Hot Pepper Sauce in the pepper growing fields of Trelawny, Jamaica. They then follow these peppers through from their germination to the point of their consumption. The purpose of such studies however, remains to "make powerful, important, disturbing connections between Western consumers and the distant strangers whose contribution to their lives were invisible, unnoticed, and largely unappreciated" (Cook, 2004; 642). As such, the point of consumption remains the intended point of political intervention.

Each of these objectives was designed to enable me to dig beneath the surface of natural gas circulations as they appear in their normalized and everyday capacities, and to trace the ways that security is performed in relation to gas's specific ontological qualities, whilst it is circulating. The third objective was designed to enable me to examine *why* different forms of action are taken upon natural gas by these different actors, at various points in space and time.

In this chapter, I describe how I conducted fieldwork in order to attend to the multiple associations through which gas is secured as a particular kind of thing, beginning with what my methodological approach owes to actor-network theory, before moving to discuss how the particularities of gas's materiality (and the specificity of the forms and practices of gaseous security) place in question some of the methodological injunctions associated with ANT.

Actor-Network Theory as Method

I adopt a 'follow the thing' approach that is indebted to the practice and ethos of actor-network theory (c.f. Latour, 1987, 1993, 1996a; b, 2005; Callon, 1986a; Law, 1992, 2000, 2007, 2002; Law and Singleton, 2013; Murdoch, 1998; Law and Hassard, 1999; Mol, 2002). Conceptually however, this thesis goes beyond the confines of actor-network theory to draw upon certain complementary approaches, including select work on the concept of assemblage (c.f. DeLanda, 2006; Deleuze and Guattari, 1987; Bennett, 2005) and post-humanism (c.f. Haraway, 1991; Barad, 2007). As a consequence, actor-network theory is employed in the thesis in two ways. First, it is treated as a set of conceptual tools, not all of which I necessarily utilize or endorse, and second it is employed as a methodological framework.

Specifically, actor-network theory (hereafter ANT) provides a methodological and conceptual "toolkit" (Law, 2007; 2) for dealing with "complex and the elusive" sets of associations such as the naturalized relations that constitute gas (Bosco, 2006; 136). Indeed, these associations/relations are ANT's principal focus. It conceptualizes a world that is constructed from sets of contingent relations that are formed between heterogeneous elements (known in this literature as 'actors' or 'actants'[38]), and it is through these relations that power is seen to be exchanged and dispersed. Social relations are thus simultaneously *power relations*; a notion that is drawn from Foucault's (2007) work on the 'microphysics of power', where power is regarded as being productive: it is a force that, through its exchange, enables elements to act. This power is impossible to store or to hold, and instead must be continually (and contingently) transferred between elements; elements that, for ANT at least, must be seen to consist of both human and nonhuman actors, and which must be regarded as having equal agential potential (Latour, 1993).

It is according to the arrangement of these power relations that ANT considers objects/subjects to be constructed. In ANT, "nothing has reality or form outside [of] relations" (Law, 2007; 2), and any apparently whole element/actor is performed, shaped, and made *real*, through the heterogeneous webs of associations that exist between it and other elements. They can therefore be understood as being the "effect[s] of an array of relations; the effect[s] of a network" (Law, 2000: 1)[39]. The specifics of these relations is critical, for the identities of the associated elements, the kinds of association that are formed, and the way in which these associations are arranged, all work to shape the

[38] The term 'actor' is used to refer to any entity that has the ability to have an effect (Law 2000), and the term 'actant' was later developed to emphasize the involvement of materials in the emergence of social phenomena, and to acknowledge that both humans and nonhumans will always be involved in social processes (c.f. Latour, 1999).

[39] The term "network" in actor-network theory is thus used to refer to these complex webs of relations, and the hyphen between 'actor' and 'network' indicates their inter-relatedness, for "an actor is always a network of elements" (Law, 2007: 8).

entity in question - both ontologically, and in terms of the way that they are humanly encountered and known. Moreover (and crucially for a study of security's practice), such associations are seen to affect the ways in which entities can act, action here being regarded as a product of the exchange of enabling power. It is only through the specific arrangement of power relations that entities are enabled to function in particular ways, and these exchanges are rarely equal, a situation that causes "the capacity [of elements] to act [to be] unequally distributed" (Law, 1991; 167). For these reasons therefore, ANT has been understood as a form of materialized relational semiotics, whereby elements only come to be defined and understood through the webs of associations that exist between them (Law, 2007).

As such, an actor-network approach is broadly complementary to the materialized-discursive security framework that was proposed in the previous chapter. Under ANT, heterogeneous associations are seen to contingently condition the forms of perception, knowledge, speech and action that are possible in a given moment, and security can be understood to consist of a set of practices through which these relations are organised to bring about or inhibit the emergence of relationally aleatory phenomena. ANT thus provides us with a vocabulary and conceptual framework for attuning ourselves to these relations; it enables us to develop a 'sensibility' to "the messy practices of relationality and materiality of the world" (Law, 2007; 2).

Yet the main source of ANT's value for this project stems from the methodological tools that it offers for tracing such complex webs of associations. As Latour (1996b) describes, "[ANT] is a *method* to describe the deployment of associations like semiotics; it is a method to describe the generative path of any narration" (p.374, his emphasis). As such, it has been described as a general ethos, disposition or toolkit of techniques for studying power relations (Callon, 1986a), through which researchers can effectively make visible the actors and relations that are obfuscated through processes of translation and naturalization (Law, 1992).

There are three elements of ANT as method that I consider to have particular value for attending to the objectives of this study, the first of which regards the emphasis that ANT places upon the practice of following. Indeed, ANT's primary methodological proposition is to "follow networks and to study the materials they are made of and the relations established between these materials" (Murdoch, 2006; 73). In this process, the aim of researchers should be to "learn from [materials, bodies, things] not only what they do, but how and why they do it" (Latour 1999; 19). This involves going along with the elements in focus, observing the way that they form associations with other bodies, materials and things, and investigating the reasons that lie behind the interactions between these elements. In this regard, ANT complements all of the research objectives of this thesis, for it advocates an approach through which gas can be followed and through which the *when's*, *how's*, and *why's* of security's practice can be documented.

On its own however, this tool does little to differentiate ANT from other 'follow the thing' approaches. Yet ANT's approach becomes more distinct when we consider a second ethos, or instrument in its toolkit: its insistence that researchers must stay "as open minded as possible about which elements will link together, how strong the links will be, what types of action will arise, and thereby how spaces come to be arranged" (Murdoch, 1998; 369). This involves abandoning prior assumptions about who or what should be considered a security actor, what should or should not be considered a security practice, and what is or is not, a referent object. In this respect, ANT is well-suited for attending to the first research agenda of this thesis: exploring security's performance in relation to the specific ontological qualities of circulating elements, rather than simply applying existing generalizations to an empirical context.

Finally, and closely associated to this previous practice, ANT contributes the 'principle of generalized symmetry' (c.f. Callon, 1986a; Latour, 1993). This principle asserts that materials should be afforded the same attention as humans, and should be considered to have equal potential to act (at least in the first instance). In accordance with this tool, ANT requires researchers to reject the anthropocentrism that is often inherent within social scientific accounts, and instead demands that we treat all actors equally, making no assumptions or assessments of their relative importance until after data collection (Latour, 1993). I consider this emphasis on the heterogeneity of agential elements and their often surprising vitality to be particularly useful for attending to the material liveliness of natural gas, and for enabling me to explore the way that other materials and things become involved in performing security around gas across its travels. Having established the methodological ethos/tools underpinning this thesis, I now turn to an issue that haunts any ANT inspired work that seeks to follow constitutive associations – how to bound and thus limit the study.

Scope of Study

Gas transport networks span the globe. They stretch over oceans and continents, reach across national borders, and link up with thousands of sites in which gas is extracted, processed, and consumed. In the UK alone, the domestic gas transport network consists of literally thousands of miles of pipes that stretch out rhizomatically to form a dense capillary-like fabric that covers the majority of the country. As such, following gas over the full extent of its circulatory journeys is an impossible task. In order to construct a research project that was practically achievable, I have had to draw clear spatial limits around the gaseous journeys under observation. I consequently chose to focus upon gas circulations within the UK. My fieldwork entailed following gas's movement through different onshore gas infrastructures, identifying the points at which it arrived onshore[40], and tracing its movements between these points and the different locations in which it was consumed or released. In this way, I avoided limiting my analysis to a number of fixed nodal sites, but instead could document the ways that security was practiced around natural gas throughout these circulatory journeys.

Given the scale and rhizomatic nature of parts of the UK's gas infrastructures however, simply restricting my fieldwork to a UK context was not enough to make the project practically feasible. Additional cuts consequently had to be made to the scope of analysis, each of which broadly related to one of the four semi-discrete infrastructures that make up the UK's gas transport networks.

The first of these infrastructures concerns the various, dispersed facilities that relate to gas's onshore reception, processing and storage before it enters the UK's national gas transport networks. These facilities include the processing terminals at which this gas is chemically altered before it enters the gas transport networks, the LNG terminals at which liquefied natural gas is received and converted back into gaseous form, and the multiple gas storage facilities that are located across the UK. These sites are all managed and operated by different private interests. Processing terminals are the responsibility of extraction companies such as Shell, Total, ExxonMobil and BP. There are then three LNG processing terminals: Isle of Grain (operated by National Grid), Milford Haven (a joint venture between Petronas and Shell), and South Hook

[40] There are 7 processing terminals at which gas arrives in the UK. There are also a number of liquefied natural gas terminals, and a series of international interconnectors (pipelines) through which gas is delivered to the UK market. A small amount of bio-methane is also introduced to the network at a number of sites around the UK. These were also included in this study.

(co-owned by Qatar Petroleum, ExxonMobil and Total). Each of the UK gas storage sites are run by separate private companies.

Given the number of different organisations that are involved in receiving gas and preparing it for transport, the time investment required to gain permissions to visit each of these sites was beyond the scope of this study. Such time constraints were also enhanced by the fact that many facilities are sites of 'Critical National Infrastructure'[41], and their security clearance requirements meant that gaining access to these sites was a prohibitively time consuming endeavour.

Whilst I could have excluded these facilities from the scope of my research, it became increasingly apparent during fieldwork that the work conducted in gas processing terminals had significant implications for the way that security was being performed elsewhere downstream. Within gas terminals, the chemical structure of natural gas is manipulated in ways that strip it of certain threatening capacities, and this directly affects the kinds of gaseous phenomena that can occur throughout its travels. As such, it conditions the forms of action that are taken upon it later in its journeys. As a result, I deemed it necessary to visit one of these terminals, and organized a visit to Shell's processing terminal in St Fergus, Scotland. This site receives and processes a quarter of the UK's total daily gas supply[42], and is consequently a site of critical importance for the continued functioning of the UK gas infrastructure.

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[41] A site of critical national infrastructure is defined by the governments' Centre for the Protection of National Infrastructure as: "Those critical elements of national infrastructure (facilities, systems, sites, property, information, people, networks and processes), the loss or compromise of which would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences or to loss of life" (Centre for the Protection of National Infrastructure, 2016).

[42] Evidence from interview with operations manager at St. Fergus gas processing terminal, Shell, 2015.

As part of this visit, I was given a full day tour of the terminal facilities. I was shown gas's point of arrival on the mainland (see image 3 in appendix C), and was able to follow it through the various processes that were conducted upon it, observing the different actions that were being taken. Throughout the tour, these processes were explained to me by a guide, who detailed the reasons behind the different forms of action that could be taken at different times, the various kinds of gaseous phenomena that could possibly emerge during terminal operations, and the forms of action that would consequently be conducted in response. The tour was then followed by a 2-hour interview with the operations manager for the terminal.

The second system that was explored during fieldwork was the National Transmission System (NTS)[43]. After gas is received by the infrastructures above, it then enters the NTS. This system consists of a series of large, high pressure pipes that transport processed gas around the country in large volumes, and gas is taken off from this system at various regional locations, where it is then piped by other, smaller, networks to individual properties. National Grid currently operates this system. Given the major role that the NTS plays in the onshore transport and governance of natural gas, the way that security is performed around the gas traveling within it became a major focus of this study, and efforts were taken to examine its processes as extensively as possible. I organised numerous visits to National Grid's headquarters in Warwick[44], conducted multiple interviews with National Grid staff, attended a range of conferences, briefings and industry events that related to the governance of gas within the NTS, and participated in a series of site visits to different locations across this system where particular actions were being taken

[43] For a diagram of the NTS, please refer back to figure 1, on page 16.

[44] I only had one official 'tour'/visit of National Grid's headquarters, but each interview with National Grid staff took place there, and would nearly always involve me being shown new parts of the building, unexplained aspects of daily NTS operations, and the organizational structure of National Grid.

upon the gas. A full list of the data produced and sites visited can be viewed in Appendix A.

The third infrastructure that was examined in this thesis was the distribution networks. There are five 'local distribution networks' that serve regional areas across the UK, and these are owned and operated by separate network operators (see figure 2 on page 17). These networks consist of dense rhizomatic tangles of pipes that take gas off the NTS and deliver it to consumers across regional areas. Their pipes are split into a variety of different pressure tiers, and these pipelines take gas off from the NTS at high pressure, gradually reducing it over the course of the gas's journey to households.

Due to the spatial extent of these networks (they consist of literally thousands of kilometres of pipes that sprawl out in a capillary-like fabric covering large areas of the country), and due to the time investments that would have been required to conduct research with all 5 networks, I opted to restrict my analysis to gas's circulations within just one; the North of England system that is run by Northern Gas Networks. Whilst it is likely that there will be some minor variances in practices between these networks (and regardless, I am not seeking to provide a representative account), the day to day operations of these systems are often very similar, according to practitioners that I met at various industry events[45]. They often outsource to the same contractors, buy and install the same equipment, and they all have their conduct regulated by OFGEM according to the same criteria.

[45] I participated in many informal conversations at industry events, where representatives of multiple networks were present. Many of the people I interviewed from Northern Gas Networks and National Grid also had experience either working for, or working with, other network operators too, and were able to point me towards similarities and differences in practice.

Fieldwork within this system entailed conducting a series of interviews with different members of staff from Northern Gas Networks, as well as participating in numerous site visits to different locations where particular kinds of securing actions were being taken upon the gas. I also attended a range of industry conferences and events that related to the governance of gas within these distribution systems, and which explored the particular security challenges that the gas distribution industry was currently facing. Substantial archival research was also conducted to learn about the history of these networks, for many of the current challenges that these systems face have resulted from their advancing age and from their having been initially designed to transport town gas, rather than the natural gas that is in circulation today.

The final infrastructural system that was examined during fieldwork was the parts of the gas transport infrastructure that are owned and operated by domestic consumers. Whilst the operators of distribution networks are responsible for the gas up until the point at which it enters properties, internal pipework and the appliances that are used to burn the gas fall under the responsibility of the property owner and their contracted gas fitters. In the case of an incident in which gas escapes, responsibility broadens to include a range of other actors. National Grid operates a national gas emergency hotline. Distribution network operators will despatch emergency gas engineers to survey the site, and in the case of the realization of a fire or explosion, blue light services (the fire and rescue service, police, and ambulance services) and local authorities will take responsibility for dealing with the incident.

Having already limited my analysis of gas's journeys through distribution networks to the North of England, I chose to similarly restrict my analysis to its movements across this part of the country. Research involved conducting interviews with the actors listed above, which in the case of this regional area included Durham and Darlington Fire Service, Durham Constabulary, the Northeast Ambulance Service, Durham County Council, Northern Gas Networks, and National Grid.

In addition to these interviews, I also drew upon a series of other data sources. Documents such as the contingency plans and the operational arrangements that had been drawn up by these organizations to deal with gas incidents, along with post-incident investigation reports and industry standards helped me to develop an understanding of the different actors that come to be involved with managing gas within these networks, the way that they take action upon the gas, and the reasons for these particular actions – particular forms of feared gaseous phenomena being outlined within many of these documents.

Also contributing to this analysis, a number of site visits were conducted that had particular relevance for the way that gas is governed in these parts of the gas infrastructure. These visits included a trip to a material failures analysis laboratory (owned by DNV-GL, and which is used to forensically investigate the causes behind casualties and fatalities related to gaseous phenomena), and a series of visits to sites across the North of England where gas leaks had been reported, and where I observed the way that distribution companies attempted to assess these leaks for risks, with reference to the specifics of the properties nearby.

II. Burrowing

Despite these arrangements however, natural gas proved to be a particularly challenging element to follow. ANT places heavy emphasis upon observation as the primary strategy through which an element's associations can be traced[46], but gas presents difficulties for observing it, due to a number of its troublesome material qualities (such as its invisibility, intangibility and natural odorlessness), and also because of the security practices of concealment that are conducted around it. As a result of these challenges, my fieldwork began to take on a quality that perhaps has more in common with *burrowing* than with following. It became like Deleuze and Guattari's (1987) rhizome: as I tried to observe the journeys of gas, I encountered roots, rocks and other obstacles that caused my fieldwork to take unexpected twists and turns, and that led me to follow gas backwards and forwards, horizontally and vertically. As such, far from simply excavating these gaseous security practices and laying them bare for all to see, this study provides an account that is more tunnel-like, its vision curtailed by the practical limitations and obstacles it encountered.

Troublesome Materialities

"I stood in the rain with three engineers from Northern Gas Networks, the four of us huddled around one of their vans. By our side, a series of muddy holes had been dug in the ground, revealing sections of an old and rusty cast iron mains pipe that was transporting gas to a nearby university college[47]. "You know, it can be a little like witchcraft trying to find these leaks sometimes", one of the engineers explained to me. "Under the right conditions, gas can travel quite a long distance underground, and trying to pin-point exactly where it is coming from can be a bit of a nightmare – particularly when you have a pipe like this, which is really old and somehow didn't make it on to our [digital] maps"[48].

Extract from field notes: Gas leak at St Mary's College, Durham – 6/2/15 [Site Visit]

One of the main ways that gas presented challenges for its observation concerned the primary focus of this study: its troubling material qualities. Particular of these qualities – namely, its sensory evasiveness, its

[46] As Law (2007) has explained, ANT is essentially a descriptive practice; one through which the processes of social formation are observed and then documented.
[47] See 'Image 4' in Appendix C.
[48] Later, I asked him why certain pipes had come to be excluded. He explained to me how the paper maps that were used previously had been stored at multiple locations, and that in the process of their collation and digitization, some of them had been lost.

indistinguishability, and its hazardous vitality – presented three specific obstacles for this study's analysis. Regarding the first of these, natural gas is quite different to the papayas or bottles of hot pepper sauce that are described in classic 'follow the thing' accounts. Whilst these other elements might be relatively easy to hold in focus throughout their circulation, gas's molecules are invisible, intangible, and naturally odourless. How then, as a social scientist, was I supposed to go about following a material that almost totally evades human sensation? Indeed, as is demonstrated in the extract above, it is not just social social scientists that are affected by these traits. Gas also frequently exceeds the capacities of industry practitioners to locate and follow it – even when they are equipped with specialized tools that have been designed to render it visible.

Instead of following gas directly, I consequently opted to trace gas's presence through the associations that it developed with other actors that *were* visible, or perceptible. In ANT, every entity is seen to have multiple points of origin, and "one has to choose some of them to tell stories" (Farias and Bender, 2012; 16). Gas is no exception to this. The UK's gas transport infrastructure consists of a dense tangle of diverse interrelated materials, each of which brings with it its own unique connection to the gas in circulation, and each of which can tell us a different story about the ways in which gas is governed. In order to extract meaningful accounts, I therefore had to follow this "Ariadne's thread of interwoven stories" (Latour, 1993; 3).

In the context of this thesis, this task boiled down to identifying particular associations that were made between the gas and other actors, and following these connections (Latour, 2005), observing (or asking them questions about) the qualities of their relationships with one another, and identifying all new actors and connections that appeared in the process. In this sense, the ANT approach adopted in this thesis was similar to 'snowballing' interview sampling methods in that new participants/connections were established through the interrogation of existing participants.

Pipelines are the most consistent of these gaseous associations, and their presence is often coterminous with (or, more accurately, *co-constitutive of*) the circulation of natural gas. This relationship means that it is possible to vicariously encounter natural gas, and to identify and follow its circulatory routes, regardless of whether the gas within them can be physically seen, felt or heard. In this thesis, gas pipes consequently often became a proxy for the gas circulations themselves. From them, I could trace out the different actors that the gas came into contact with across its circulatory journeys.

In instances where gas did *not* circulate in pipes however (often when it either leaked or was released along its journey), I found that a similar approach could usually be adopted. Gas's vitality meant that numerous actors would typically swell around the location of its escape so as to attempt to 'cancel out' particular forms of threatening phenomena. Unlike the gas itself however, these attempts *were* observable, and through them, I was able to identify the different actors it became involved with, and I could observe the different ways that these actors tried to visualize gas's uncontained circulation. I was also often able to interrogate these actors as to why they took particular forms of action.

This exploration of gas's circulations external to pipes took several forms in this study. One method involved interviewing different members of National Grid, Northern Gas Networks, Durham Constabulary, Durham and Darlington Fire and Rescue Service, the Northeast Ambulance Service, and Durham County Council – in particular, members who were involved in attending to incidents where gas had escaped from particular areas of pipelines. I explored this topic over the course of multiple interviews, asking practitioners to explain to me the different kinds of uncontained gas circulation that they would attend to, the ways that they would seek to render the gas actionable and take action upon it, and the reasons that they sought to take these different forms of action.

In addition to interview data, I also found a series of documents to be useful for tracing the kinds of associations that formed around gas in the event of its escape[49]. In many cases, interviewees provided me with copies of the contingency plans and the operational guidelines that they used to attend to various forms of gas escape. These documents included texts such as the EM72 and EM74 gas escape procedure documents that are used by Northern Gas Networks[50], the standard operating procedure documents used by the fire and rescue service, and the County Durham and Darlington Civil Contingencies Units' (2012) 'Natural Gas Pipelines Emergency Plan'[51]. Alongside these documents, I also found that government legislature such as the Civil Contingencies Act (2004); the Pipelines Safety Regulations (1996); and the Gas Safety (Management) Regulations (1996) had particular significance for understanding the way that different actors formed associations with the gas, and also with one another.

Added to these particular documents, a series of publically available industry exercise reports were further useful for tracing gas's associations[52]. Every year, National Grid (in its capacity as system operator) organizes a network-wide live rehearsal around a chosen hypothetical event. Sometimes this event involves

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[49] See 'Image 5' in Appendix C for examples.
[50] EM72 refers to the Northern Gas Networks (2013) 'Northern Gas Networks' Work Procedure for First Call Operatives Dealing with Gas Escapes and Other Emergencies', and EM74 refers to the Northern Gas Networks (2010) 'Northern Gas Networks' Work Procedure for Escape, Locate and Repair Operatives Dealing with Gas Escapes and Other Emergencies'.
[51] Durham County Council and Darlington Borough Council (2012).
[52] See, for example, National Grid (2008, 2013) and Northern Gas Networks (2012).

the escape of natural gas. Following rehearsals, every organization is then required to produce a report that details the actions that they had taken, and that highlights the areas where their procedures could be improved in the future. Such reports consequently provided this study with a particularly detailed outline of how different actors came to be involved in governing gas as it circulates outside of pipes, as well as the forms of action that can be taken to visualize and control its movement, the reasons for these actions, and the challenges that the gas presented during these exercises for performances of security.

Incident investigation reports were useful for similar reasons. Following an event where gas escapes and actors swell around it, reports are often produced that detail the events that led to the emergence of these particular phenomena. A number of these reports (see for example, HSE, 1985; Benn et al., 1977) were drawn upon in this study to explore both the actions that had been taken upon gas circulations within particular incidents, and also to explore the way that attempts were made to visualize gas's circulation *after the incident*, so that actions could be taken to prevent these events from being realized in the future.

The final data source that was drawn upon in studying gas's circulation beyond pipelines took the form of site visits. The first of these involved an industry training event at RAF Spadeadam (a facility formerly used by British Gas to research suitable materials for the construction of the NTS, and now used by DNV GL for the modelling of gas explosions). Entitled 'Understanding the Causes of Gas Fires and Explosions', this event involved two days of live demonstrations, in which I and a number of industry practitioners were introduced to different forms of flammable and explosive gaseous phenomena that could potentially be realized across gas's circulatory journeys. During this event, the way that gas could come to circulate outside of pipes was visualized through a series of diagrams, lecture presentations, and live demonstrations, and through these visualizations, the organizers aimed to educate attendees to the possible risks and challenges that gas's uncontrolled circulation could present. A photograph ('Image 6'), and an extract from my field notes ('Field Note Extract 1') that were taken during this event can be found in Appendix C.

The second set of site visits then involved personally observing the swelling of actors around gas's uncontained circulations. During my fieldwork with Northern Gas Networks, I was taken on an 'escape chasing' day by their Health, Safety and Environment Manager. This involved multiple site visits across the Northeast, in which I was taken to a series of different locations in which gas escapes had been reported by members of the public. Once at these locations, I was then able to observe the different actors that became involved with gas as it circulated outside of pipes, and I was able to witness various attempts made by these actors to locate gas's escape, assess the risks that it presented, and take different forms of action upon it[53]. I was also invited to ask questions during these visits, and was consequently able to determine the motivations and interests that lay behind different actions.

In these ways, I was therefore able to explore gas's journey outside of pipes, even when the gas itself was not physically observable. Yet there were instances where gas's escape did *not* involve the accumulation of actors around it, and where the conduct of practices of visualization and security governance were not visible. Whilst gas could not be followed as easily in these instances however, it was still possible to inquire about how leaks became known to different governing actors, and why they could not be (or were not being) addressed in the same ways. As such, even though gas could

[53] See 'Field Note Extract 2', 'Image 7', 'Image 7' and 'Image 8' in Appendix C.

not be literally followed in these cases, I could often still gain a vicarious knowledge of the conditions that it needed to form in order for it to escape, and I was still able to discern some of the problems that its challenging materiality presented for performing security around it.

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The second challenge that related to gas's unique material qualities concerned its molecular diversity. Isolating a single element and following it – whilst possible with a papaya – is far more difficult to achieve in the case of natural gas. This is because gaseous molecules become inextricably mixed up with other molecules as it moves. Because of this, following a single molecule (or even a specific volume of gas) as it circulates is practically impossible. In this sense, it presents similar difficulties to those experienced by Christophers (2011) in following money: natural gas is an entity that begins to lose "its *distinguishability*" as it circulates (p. 1076, his emphasis). It is a super-spook; an elusive material that loses its shadower in a molecular crowd.

During fieldwork however, I found that pipelines could help with this problem, too. Unlike money, the "individuality [of which] both allows it to be traced, and more significantly, imparts to the process of tracing its very meaning" (Christophers, 2011; 1076), I came to regard the identification of individual molecules, or even specific volumes of gas, as being unnecessary for the objectives of this thesis. This thesis is concerned with the practices of security that are employed upon gas throughout its circulation, and I subsequently found that it was possible to identify many of these practices by using the pipes as a proxy for the circulating gas. By following pipes, and by observing the actors and practices that presented themselves along the way, I was able to observe specific forms of action that were being taken upon gas as it travelled.

Despite this, I did have to carefully watch out for instances where gas's governing actors did seek to visualize volumes of gas as they circulated. For if it became apparent that gas *was* managed at the level of molecules, particular volumes, or pockets of gas, then it would have become necessary to follow these units and to ascertain when and how they became the focus of security concerns. During fieldwork however, it quickly became apparent that gas is principally managed according to its pressures within different parts of these systems, and that it is not tracked by its governing actors on a molecule-by-molecule (or even volume-by-volume) basis. This is not to say that its movement at the level of the molecular was not significant for the practices of security that were observed to surround it – indeed, there were moments when it *was* observed to be periodically broken down into its constitutive molecules (such as after processing), yet these molecules were never followed along their circulatory journeys beyond such points of inspection. Instead, their visualization was used to alter the gas that subsequently came through the system. As such, whilst the scale of the molecular became a subject of interest in this thesis, it was not considered necessary to identify and follow any one particular molecule in order to develop an account of security's practice in relation to the gas.

The management of gas's circulation by pressure did introduce a secondary problem, however. Gas's journeys turned out to be extremely convoluted, and unlike a bottle of hot pepper sauce (which might make its way from point of production to point of consumption in a more-or-less linear manner), natural gas was found to be able to take any one of potentially thousands of routes between its points of production and consumption. Along these routes, it does not necessarily move in a linear trajectory. It travels from regions of high pressure to areas of low pressure, and this movement is manipulated by increasing its pressure at particular locations, and lowering it at others (typically through its consumption or release[54]). As a result, gas may travel both backwards and forwards along the same pipes, dependent upon its pressure in different areas at different points in time. Whilst this is interesting due to the way that it challenges implicit assumptions of the linearity of circulatory governance found in many studies of security – including the work of Foucault (2007) – it did raise further challenges for fieldwork, due to how gaseous security practices could not be simply documented by linearly following pipes from one end to another. I will return to this problem and the way it was addressed in the next section of this chapter.

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Staying with gas's troubling materiality for now however, a final further problem was presented by gas's considerable vitality, and by the dangers that this vitality presented for my own health and safety. Gas is an extremely flammable and explosive material, and its circulation consequently presents significant risks to public health. Getting physically close to gas pipes is thus a potentially hazardous exercise, and one that would have neither been permitted by the university, or by my research participants. This was not such a problem for researching gas's circulations in distribution networks, for the pressures and volumes with which gas travels are low enough to not present significant risks (indeed, a large amount of my research with Northern Gas Networks involved peering into various holes and physically observing the work that was being conducted in them). Yet in areas where gas circulates at high pressure, the risks to health are much higher. Even experienced engineers are

[54] This is a process known as balancing, and it can involve gas traveling back and forth throughout the system, dependent upon where demand is coming from.

only allowed to approach and work on high pressure pipes if the gas inside is completely removed, or has had its pressure significantly reduced. As a consequence, actually approaching gas pipes to follow gaseous circulations was, in the majority of cases, practically unfeasible.

Finding my own body physically distanced from high pressure circulations of natural gas was interesting for understanding the practices of security that are performed around gas, but it also limited the security performances that I could observe within this area of the gas network. I therefore sought to find other ways of conducting research into gas's high pressure movements – methods that did not involve putting my body at risk. As shall be described in the following section, the fieldwork eventually conducted similarly involved following the relations that surrounded natural gas, but in a way that did not involve my body being physically close to gas's high pressure movements.

Concealed Circulations

Following a more formal interview, I sat with the emergency operations manager at his 'hot desk' in National Grid House, Warwick. In front of us was laid out a detailed map of the current configuration of the NTS, and on which was depicted the different routes that gas took across the country. Also included on it were the characteristics of these routes (the pipe materials, diameters and maximum operating pressures) and the various pipeline assets that were dispersed across this network (compressor stations, off-takes, storage facilities and so forth). As he took me through gas's journeys within each section of the NTS, he explained the different ways that gas could travel within this system, as well as the kinds of actions that could be taken upon it at different points in its journeys and the kinds of risk that were perceived to be able arise on the system. Occasionally, he would bring up a series of slides on the computer in front of us, using the diagrams within them to explain aspects of gas physics and the way that different devices and control systems could be used in relation to the gas, across the NTS.

Extract from field notes: National Grid House – 8/8/14 [Site Visit]

A significant challenge was also presented to research by the way that gas circulations are intentionally concealed. Practices of concealment are performed around gas to secure its circulation in two ways: its subterranean concealment, and the public unavailability of maps of this system. The first of these regards how gas systems are buried[55]. In the UK, the ground is employed as a specific political technology for securing circulations of natural gas. Its opacity and solidity not only conceal gas's movements, but they also present a physical barrier that prevents external parties from causing damage to these circulatory infrastructures[56]. Indeed, it is through the enrolment of the ground in this way that efforts have been made to 'cancel out' both the phenomena of intentional sabotage to pipelines and also the phenomena of accidental damage. As a result, I found my fieldwork to come up against the very security practices that I sought to document. This infrastructure had been specifically designed to deter and inhibit people like me – people who wished to observe and gain a knowledge of gas's circulatory movements and the kinds of insecurities that its movements can generate.

The second concealment practice then concerned the way that gas's governing actors attempt to prevent maps and accurate diagrams of its infrastructures from entering the public domain. Maps of the NTS and distribution networks are not available anywhere online (the map in figure 1 on page 17 is not an accurate representation), and all sensitive infrastructural sites located across these networks have had their identifying details removed from publically available maps, such as those produced by Google and the Ordinance Survey. Maps of these systems do exist, but they are typically not permitted to circulate beyond company offices without authorization.

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[55] This practice is adopted in the UK and a number of other countries, but in areas of the world where there is either very low population density (such as in parts of Canada or the United States), or where there is high seismic activity (such as in Chile), natural gas may be transported overland, either by surface-level transmission pipes, or by pipes that are suspended above the ground to reduce the risk of damage being incurred due to the grounds' movements.
[56] In addition to burying gas, nondescript buildings, walls, fences and earthen mounds are often employed to conceal pipeline assets that rise above the ground.

For a study that is dependent upon using gas pipes as a proxy for these invisible, intangible, and (at least whilst in the NTS) odourless, circulations of natural gas, the combination of these two practices presented serious observational challenges for documenting the security practices that are conducted in relation to natural gas. Indeed, these practices of concealment are so successful, that as can be observed in the extract that opened the previous section, these pipes and the gas circulations within them can sometimes evade the perception of practitioners, even when they are equipped with digitized maps[57]. As a consequence, I found myself to be a geographer without a map, and a social scientist without a somatically perceptible object to study.

The solution I adopted involved identifying a number of more easily visible associations that gas developed, and from these teasing out the "Ariadne's threads" (Latour, 1993; 3) of relations that gas developed in connection to them. In practice, this involved initially identifying as many gaseous associations as possible – principally through online research. As is required by ANT, no presumptions were made as to who or what would do the work (Latour, 1987), and provided these associations fell within the spatial parameters that were established by this thesis, they could potentially exist between the gas and any number of different organisations, people, materials, locations, and documents. Many of the actors first identified were located above the earth's surface (such as energy companies, operational facilities, industry institutions, and so on), and whilst this process began fairly simply, the

[57] One of the more peculiar security practices that I encountered during fieldwork regarded pipes such as these that had been excluded from the digital maps used by distribution companies. When distribution engineers know that a gas pipe is present but it is not on their maps (usually because a property will use gas, but the gas main feeding that property is not on their systems) and is not metal (so therefore not identifiable with a metal detector), a common (but unofficial) practice is to use divining rods to ascertain the location of buried pipes. I initially thought this was a joke, but it was subsequently backed up by multiple disconnected sources during fieldwork. For an example of an email exchange that I had with an engineer regarding this, see 'Image 10' in Appendix C.

actors, contacts and associations seen to surround the circulating gas quickly proliferated, each then becoming incorporated into the scope of the study's analysis.

Indeed, one of the more successful strategies in these early stages involved applying for student membership to various energy, gas and pipeline industry working groups. These institutions included the Institute for Gas Engineers and Managers (IGEM); the UK Institute for Trenchless Technology (UKITT); the Energy Institute (EI); the Pipeline Industries Guild (PIG); and the Durham Energy Institute (DEI). Membership of these institutions enabled me to access databases of group members and industry professionals, and from these I could then identify contacts that held positions within relevant departments of different organisations such as Northern Gas Networks, National Grid, and DNV-GL. Membership also permitted me to attend a range of industry events, including conferences (which covered topics such as the current operational challenges faced within the gas transmission and distribution networks, and preparations for emergency scenarios within these networks), expositions (in which engineering and technology firms advertised pipe materials and assets for use within transmission and distribution systems[58]), and perhaps most valuably, group visits to infrastructural facilities.

Eventually, this led me to develop contacts with people who worked in the St Fergus gas processing terminal, National Grid and Northern Gas Networks, who had access to detailed maps of these pipeline infrastructures, and who were willing to sit down with me and take me through the various forms of action that were conducted upon gas at different stages in its journeys within these systems. These could be understood as constituting a form of 'enriched

[58] These were particularly useful, for employees would often describe the functions and limitations of existing hardware and software, and were often keen to introduce me to other relevant contacts that worked in different areas of the industry.

interview' (Dowling, Lloyd and Suchet-Pearson, 2015, 2016), and as is described in the extract from my field notes above, this process of enrichment allowed for the development of extremely detailed analyses of the various routes that gas takes, the way that gas moves through these systems, the ways that these movements are visualized and rendered actionable by different actors, and the ways that different forms of action are taken upon them.

Such maps also depicted gas's journeys at various scales. Some provided visualizations of gas's nation-wide circulatory movements through the NTS, whilst others consisted of technical drawings of gas's movements through small local areas, and even individual facilities (see 'Image 11' and 'Image 12' in Appendix C). By attending to these different circulatory routes so meticulously, and by asking research participants to identify all of the different forms of action that could be taken upon gas across its journeys at different scales and why, I was able to develop a highly detailed understanding of the way that security comes to be performed in relation to gas across its circulations, and to identify many of the different actors that become involved in these performances. As such, two of the most substantial problems for research were able to be overcome. Not only did I circumvent the difficulties that I faced through the concealment of UK gas circulations, but I also came to research the security practices that surrounded high pressure gas circulations without putting my body at risk.

These map-based exercises also me helped to address the challenge presented by the convolutedness and non-linearity of gas's movements within these networks. In addition to tracing the different forms of action that could be taken at junctures along these pipes, these practitioners emphasised the way that gas moved non-linearly within them, and the way that actions were taken up and down these networks, dependent upon these movements. This was also supplemented by visits to both the Gas National Control Centre for the NTS (the control room through which gas's circulations at the national scale are visualized and managed), and also the Northern Gas Networks' Regional Control Room, where gas's circulations are similarly mapped at a local level. Through these visits, I was able to observe the way that gas's pressures across these different networks were visualized, and the way that different forms of action were taken upon the gas in different locations, dependent upon these pressures and the directions and volumes in which the gas was consequently moving.

Additionally, the governing practices surrounding gas's circulations were traced through other means. As new actors were identified via online research, interviews and discussions, a plethora of additional actors, interests and actions that were associated with gas's circulation began to emerge. These associations included legislature and industry standards (which often established particular ways that gas's relations should be arranged in different contexts), different types of pipeline material and asset/device (such as meters, valves, pressure regulators, compressor stations, inline inspection devices, gas detectors and so forth), and various different industry organizations (such as Linewatch and the UK Onshore Pipeline Association, UKOPA). Each of these different associations were also investigated for the ways that they variously became related to gas, and were interrogated concerning the reasons behind the different forms of actions that they took upon the gas (either through interviews, email exchanges, documentary analysis or site visits). Again, these associations were typically productive of a range of further associations that would likewise become incorporated into this study.

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Finally, gas's concealment presented a challenge regarding the ethics of conducting research into UK pipeline security. In trying to document an infrastructure that is so meticulously concealed through specific security practices, I ran the risk of actively undermining security's performance. As a result, there was a danger that my own research would become perceived as being a security threat, and that similar attempts to 'cancel it out' would consequently be made against it.

Indeed, concerns expressed by participants included the risk of this thesis facilitating the sabotage of critical pipeline infrastructures, and also of it potentially enabling pipes to be illegally and dangerously tapped into so that gas could be stolen. As such, I had to carefully navigate the tension between the interests of my fieldwork and the interests of gas's security actors. Specifically, I had to provide participants with assurances that all information relating to the locations of gas circulations would be omitted from the manuscript[59], and I also had to promise to ensure that all fieldwork data would be encrypted and stored securely on non-networked hard drives.

Reflections on Methods for Following and Burrowing

In addition to the fieldwork challenges that were presented by gas's materiality and concealment, I also encountered a series of problems that related to my research methods. These can be broadly summarized as issues with the specific methods that I employed in my research, and the challenges that were presented by my own positionality as a researcher within these webs of gaseous associations. These different methodological issues have consequently resulted in this thesis not claiming to reveal gas's relations, but to

[59] The maps included in Appendix C ('Image 11' and 'Image 12') have been reproduced with permission. They have either been heavily cropped, or have had specific information that would enable their location to be identified edited out. No detailed maps of the NTS were permitted out of the facilities I visited.

instead weave a partial and situated narrative of the associations observed whilst burrowing.

In terms of the problems that these methods presented for my fieldwork, semi-structured interviews, documentary analysis, and site visits each were found to have specific benefits and drawbacks regarding the forms of gaseous association that they enabled me to observe within particular contexts.

Semi-structured interviews were found to be particularly helpful for generating rich and detailed data concerning the actions taken upon circulations of natural gas. Indeed, the way that these interviews involve two-directional synergetic conversation made them especially well-suited for coming to terms with the complexity of gas's associations and with the dense technical language that is associated with its governance. This was particularly helpful during the early stages of my research. In the interview extract below for example, I can be seen struggling to understand the relationships between category 1 and category 2 responders in the event of a serious gas incident.

Speaker 1: That was going to be a question of mine - I mean, what is the role of the category 2 responder?

Speaker 2: I mean, I have no idea …when the civil contingencies act was put in they seemed to think that all…category two responders, which is ourselves, the water companies…or the utilities, sort of all getting together to deal with a major civil crisis...but…what do we do? You know, we respond to and deal with gas emergencies. You know (laughs bemusedly). I find it very difficult to understand how category two responders are meant to be part of this sort of community of…of responders who, all of a sudden will leap into action.

Speaker 1: That's really interesting. Chatting to the guys from the blue light services, they seem very clear on their particular roles…

Speaker 2: Of course, but that's their job!

Speaker 1: …OK. But it is really interesting to hear that the category 2 responders don't feel as if it is such a well-defined relationship though. I can see in say, something *like a big event that National Grid might be involved with, they will have a mobile command unit to manage flows and stuff…*

Speaker 2: They probably wouldn't manage flows from their mobile unit they would manage it from their own system

Speaker 1: Oh. What are mobile command units used for then?

(Interview: Health, Safety and Environment Manager, Northern Gas Networks, 2015)

In this instance, the flexible two-way nature of semi-structured interviews can therefore be seen to be helpful for coming to terms with the technical language that is used within these networks, and for identifying the various elements that came to play a role in these security performances.

A further significant benefit of these interviews involved how they were typically held in participants' offices. This often had benefits, for respondents had at hand relevant information and resources that they were willing to share with me (including photographs of assets, network maps, asset diagrams, figures and database entries, and computer software), and they would often incorporate explanations of these, tours of their facilities, and also demonstrations of software and control systems, into my visits. Furthermore, it also often meant that they would introduce me to other colleagues who were involved in managing gas in different ways. This was especially useful, for it led me to identify new relevant actors, associations and actions, and it enabled me to follow these up with further interviews, site visits and documentary analysis. In this sense, many of my interviews became enriched or enhanced (Dowling, Lloyd and Suchet-Pearson, 2015, 2016), and they often took on the form of a form of site visit, allowing me to observe more of gas's various associations and the ways in which it gas was managed on a day-to-day basis.

Despite these benefits however, semi-structured interviews also had drawbacks. Most significantly for a study of the socio-material relations surrounding natural gas, they privileged human actors that can verbally express themselves. Whilst interviews are never simply just encounters with humans – they frequently draw upon, and indeed, are made possible through, associations with other material elements, there is a risk of certain material actors being misrepresented or ignored within interview conversations, particularly in the case of 'humble' or 'banal' materials that may become "invisible and unremarked upon, a state they usually achieve by being familiar and taken for granted" (Miller, 2010; 50).

As numerous materialists, including Lorraine Daston (2007) and Jane Bennett, (2005, 2009) have emphasised however, materials and nonhuman actors are not speechless, and they do not have to rely upon interviews for their representation. Indeed, they come to speak through their abilities to call a society of other things into existence (Daston, 2007); societies that may include human associations (such as in interviews, when they press upon interviewees' memories and come up in conversation), but that can also consist of their assertions on a multiplicity of other elements. Gas, for example, may speak of its presence through its associations with unearthed gas pipes, or through gas company vans. Yet usefully for this research, gas also expresses itself through a plethora of documents. These included legislative documents, industry standards, policy documents, annual company reports, live-practice exercise reports, meeting minutes, gas fitting manuals, operations handbooks for specific pipeline devices, promotional materials for industry services and equipment, schematic maps and infrastructural plans, and various forms of archival materials on topics such as past and present gas industry practices and government policy. The analysis of all of these different materials provided yet another way of tracing the relationships that gas formed with different organisations, bodies and materials. Often the level of detail within them also typically greatly exceeded that which could be expected of respondents to provide in the time available in interviews. As such, they often enabled me to develop an extensive understanding of many aspects of the functioning of gas infrastructures and governance systems that I would otherwise not have acquired, and they also frequently assisted me in identifying further actors that had either been overlooked in interviews, or that had not been observed during site visits.

Yet documentary analysis similarly had drawbacks, too – again related to the form of gaseous associations that they made observable. Typically, texts provided accounts of how actors were *supposed* to act in given situations, rather than documenting the actual everyday practices of actors involved in performing gaseous security. Whilst this is interesting for the way that attempts are made in these documents to structure the conditions through which particular forms of gaseous phenomena can emerge, any instances where these regulations and arrangements differ from these actors' actions risk being omitted from accounts.

In contrast, site visits are not subject to this limitation. Site visits took a form similar to ethnography in this study, in that the objective was to specifically observe how actors behaved in relation to one another within particular environments. Yet unlike ethnography, these visits did not take place over an extended period of time, but were typically short – lasting anywhere between 30 minutes and a couple of days[60]. The reason that they were chosen over ethnography was due to a matter of practical necessity. Because of the number and geographical spread of the sites that I wished to study, and also because I had to be supervised during fieldwork due to security and health and safety

[60] Typically, they lasted several hours.

concerns, my observations were typically limited in their duration to the amount of time that participants were willing to spend taking me to different sites and supervising my observations.

Numerous site visits were arranged as part of my fieldwork. Typically, they would either comprise of group events that were organised by an industry body (with which I would gain prior permission to conduct research), or they would consist of supervised site observations that I arranged directly with research participants. During these visits, I would attempt to identify and document all of the bodies and elements that presented themselves, thickly describing their arrangements, the forms of relation they established, and the kinds of action that were undertaken upon the gas during these encounters. Where permitted, photographs were also taken for future reference.

Site visits also had the benefit of permitting informal semi-structured interviews to be conducted whilst I was in the field. This had value, for it enabled me to question participants about the different roles that people and materials assumed within gaseous security performances, and it allowed me to inquire about the reasons and motivations behind their actions. Furthermore, whereas it may have been easy for participants to overlook the role of materials whilst speaking to me in their offices (and it may have been hard for me to become aware of any omissions that were being made), they also had the benefit of reminding participants of these elements through their physical presence. As such, site visits often entailed rich explanations of the functions of different elements that I had not previously identified, and they also made it simpler for me to identify any omitted actors, due to the way that I found myself face-to-face with these unknown elements, and was able to immediately learn about these through further questioning.

Like all of the methods employed in this thesis however, site visits were also limited in the kinds of data that they could produce. Most significantly, they were limited in their ability to deal with the challenges that were presented through the burying of gas pipes. Indeed, within this thesis's fieldwork, site visits had to be conducted at locations where gas infrastructure had either emerged from the ground or was excavated, or where gas had escaped and actors had visibly grouped around it. As such, site visits alone were not sufficient to enable gas and its associations to be followed across its circulatory journeys.

When used in conjunction however, many of the limitations that were present within these individual methods were able to be overcome, and a detailed account was consequently able to be produced of the way that security is performed in relation to gas's circulation. The presence of these limitations mean that it is never possible to produce a comprehensive account, however. Different associations may not have presented themselves during the times when my fieldwork was conducted, others may not have occurred in the locations where these methods were employed, and others may have totally evaded the 'torch-like' field of vision that was illuminated by them. Indeed, some of gas's associations may have totally exceeded human capabilities to perceive them altogether.

This is not a failing of my fieldwork however, but a recognition that it is *never* possible to comprehensively reveal the subjects of our inquiries through research. Instead, we are forced to appreciate how, as researchers, we are individually positioned within a world that is in its emergent becoming (Barad, 2007). What was possible for me to observe during fieldwork was not only conditioned by my position within space and time, and by the tools and associations that were available to me in that moment, but they were also affected by the limits of my own individual perceptive capacities. Indeed, whilst gas's invisibility may be common to human senses, my personal position as a social scientist who was not trained in engineering or the operation of pipelines may have meant that certain associations and nuances of these gaseous security practices evaded my perception. As such, what it was possible to know within a given instant was conditioned by my positioning. Indeed, as Barad summarizes; "Knowing is not a bounded or closed practice, but an ongoing performance of the world": it is "a feature of the world in its differential becoming" (2007; 149). As researchers, we will therefore always be reduced to burrowing, in some manner.

In highlighting such limitations to observation however, I diverge from Latour's claims regarding what kind of entities matter (2005; 150). Latour argues that we should ignore elements that cannot be perceived, stating; "What would be the use of adding invisible entities that act without leaving any trace and make no difference to any state of affairs?" Yet in contradiction to Latour, I contend that acknowledging the potential existence of associations that we might not have the ability to perceive is critical for security studies. The securing actions that are taken to protect referent objects from sources of known and unknown contingent threat often cannot be understood without appreciating the possibility of 'invisible' entities that evade our perception. Indeed, these may never be encountered directly, but may have vicarious 'knock on' effects on other elements that have significant implications for the forms of phenomena that emerge. As such, there may be much in the world that has effects on human bodies and other elements, but which may exceed the ability of individuals to perceive or understand them at different points in space and time, and for this reason, gas circulations cannot ever be simply excavated and followed. Instead, we are limited to burrowing down to them, encountering rocks and obstacles on the way, and peering through the murky gloom to take an incomplete and partial glimpse of the associations that surround it.

III. Conclusion

This chapter has outlined the methodological approach that is adopted in this thesis. Specifically, it has described how my fieldwork was conducted according to a methodology inspired by classic 'follow the thing' studies and by the methodological literature on ANT. This approach involved following natural gas as it circulated across the UK, tracing the relationships that it developed with other elements, and identifying the forms of securing action that came to be taken upon it during these circulatory journeys.

Specifically, I described how gas's associations and the practices that were conducted in relation to it came to be observed through the application of three specific methods; semi-structured interviews, documentary analysis, and a series of site visits. I explained how these techniques permitted me to produce an account of the way that security is performed in relation to gas as it circulates, and how they enabled me to describe the manner in which a range of different interests and motivations came to structure the performances of security that were observed.

This approach was designed to enable me to pursue the two research agendas outlined in this thesis's introduction. Regarding the first of these, I seek to document the way that gas's specific ontological qualities influence the way that security is performed in relation to it. Regarding the second, I seek to explore the way that gaseous security performances come to take place *across* gas's circulations, as it moves between nodal points.

I have shown that ANT is a valuable tool for pursuing these agendas. I have argued that the emphasis ANT places upon following and tracing the relations between heterogeneous elements make it well-equipped for studying the material-semiotic relations that shape and condition the formation of natural gas. I have also suggested that its insistence upon rejecting prior assumptions about which elements will act, how they will act, and why they act, makes it well-suited to a study that seeks to avoid adopting established conceptualizations of security, due to how these frameworks have tended to erase the specific material qualities of circulatory elements.

The materiality of gas and the way in which it is concealed through specific security practices was however, shown to pose some difficult challenges for an approach that is based upon practices of following. Specifically, I described how various aspects of gas's materiality and concealment, as well as the inherent limitations in my own research methods and the influence of my own positionality, mean that it is impossible to produce a comprehensive, or ever truly 'complete' account of these gaseous security performances. As such, rather than following gas and excavating its circulations for all to see, I have described how I have had to *burrow* rhizomatically, encountering rocks, roots and other obstacles along my way, my field of vision becoming impeded by a series of methodological and positional constraints.

In the following chapters, I document the actors, practices and interests that came to be observed during this fieldwork, and describe the various ways that gas consequently becomes subject to a series of security performances throughout its circulation.

4

Rendering Gas Actionable

I. Introduction

Rendering entities actionable is a precondition of security. To systematically take action upon an element to facilitate, cancel out, or compensate for particular kinds of phenomena that may emerge in relation to it, attempts must be made to understand their ontological constitution and the ways that particular phenomena form. As Dillon (2007) puts it; to conduct securing actions, governing actors must first "take into account the nature of the thing to be governed" (p.45). All performances of security consequently involve attempts to develop bodies of knowledge around the objects to be secured, and different knowledge practices can greatly affect the forms of action that may be taken upon those elements. It is for this reason that the practices through which particular bodies, materials and things are rendered actionable within contemporary practices of security have become a focus of concern within recent critical security studies debates (c.f. Amoore and Hall, 2009; Dillon, 2007; Adey and Anderson, 2011a; Anderson, 2010).

As Gavin Bridge (2014; 3) has acknowledged, "the securitisation[61] [of energy similarly] depends on knowledge practices (definitions, measurements,

[61] Bridge's (2014) emphasis upon discourse and use of the term 'securitization' here does not limit the applicability of his comments to linguistic accounts of security. All forms of security

assessments, technologies of visualization)". As a consequence, the securing of natural gas is dependent upon similar kinds of practice. When we consider the materiality of gas (rather than its abstract depiction in graphs of its extraction rates, projected consumption, and estimated future costs)[62] however, it quickly becomes apparent that it is a material that provides a particularly interesting case through which to examine these kinds of knowledge practice.

This is because natural gas is quite unlike many of the materials that have formed the focus of other materialist enquiries. It is, for example, distinctly different from Jane Bennett's (2009)[63] black plastic glove, her discarded bottle top, or her dead rat. Unlike these materials, it frequently refuses to present itself readily for human sensorial experience. During my research I have not *seen* natural gas. I have not smelled it (at least, not before an odorant was added precisely so that I could smell it). I have not touched or tasted it. On occasion I have heard it, but then only in ways that are not obviously attributable to it: as a whisper or shiver in a pipe, or as a quiet, barely noticeable hiss from a dank and muddy hole. Apart from these rare moments, gas has remained silent, invisible, intangible – imperceptible. It is a material that is innately immune to human sensorial discernment; it exceeds our senses and refuses to grant us a direct audience. It is therefore unlike Bennett's collection of forceful materials. It is unable to seduce me into contemplation,

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require particular means of rendering their objects of concern knowable in order to take action upon them.

[62] For a good example of how different energy products are rendered visible in these dematerialized ways, see the Wicks report (Wicks MP, 2009).

[63] Jane Bennett's (2009) book, "Vibrant Matter: A Political Ecology of Things" has been a particularly influential text in human geography's recent 'material (re)turn' (Whatmore, 2006). In this work, Bennett draws attention to the vitality of matter, and to the way that material 'things' may become implicated in political events. In her opening chapter, "The Force of Things", she highlights the collective agency of the collection of material elements that I describe above (a black plastic glove, a bottle top, a dead rat) and demonstrates how these materials collectively pressed upon her senses and inspired her to write her materialist critique. Given the emphasis I place upon the role of materials in security's performance and their vitality, she therefore provides a logical entry point for a materialist analysis of gaseous security performances.

spur me into action, or motivate me to write, merely by its presence. Its physicality has little somatic affect.

This imperceptibility presents particular challenges for governing gas, for if a material defies human senses so entirely, then how can its 'nature' be accounted for? How has gas come to be an object that is known; an object that can be governed and commercialised? These are the questions that I seek to address in this chapter. In the pages that follow, I explore some of the difficulties that gas presents for rendering it actionable, and I demonstrate how a complex set of practices have consequently been developed around these difficulties to define, measure, assess, and visualize gas circulations so that securing actions can be taken upon them. Following the central claim of this thesis – that the ontological constitution of the entities in circulation should be the principle object of study within studies of security, the specificities of the actions employed to render gas's troublesome materiality actionable are emphasized here. Indeed, without attending to the specificities of gas's dynamic materiality, I suggest that it is impossible to understand how this material is rendered actionable and how it comes to be secured.

In section II, I begin a discussion of the material peculiarities of natural gas and the different ways that these qualities may force us to reconsider how materials can be known and governed. Drawing upon the work of Jane Bennett (2009), I first acknowledge the similarities between gas and the materials that have typically appeared within materialist studies. Like the black plastic glove and her other elements, I suggest that gas is humanly encountered through its intra-actions with forceful heterogeneous collectives, and that through these relationships, gas is able to vicariously press upon human senses in ways that render it intelligible. Where gas is distinct from these other materials, I suggest, is in the spatial and temporal incoherence of its affective encounters with humans. These claims are then developed through a brief exploration of some of the ways that humans have encountered gas historically – by examining examples of gas-human encounters prior to the systematic application of particular gaseous knowledge practices, I suggest that we can most clearly observe the peculiar qualities of natural gas that have made it such a challenging material to render actionable and secure.

In the following two sections of the chapter (sections III and IV), I describe how a system of practices has been developed to systematically render natural gas more coherent so that different forms of action can be taken upon it. In section III, I argue that gas's rendering actionable (or '*securable'*) is partly achieved through attempts to map out what Manuel DeLanda (2013) describes as 'possibility spaces'. DeLanda uses the concept of the possibility space to serve as a spatial metaphor for the constellations of possible relations that exist between the internal elements that constitute a given entity, and the relations that this entity may form with other external elements. He argues that a virtual multiplicity – a plethora of possible relations – surrounds each entity, and that it is through the actualization of certain sets of these relations that different phenomena (desirable or undesirable) can come to emerge. Building upon this premise, I illustrate how maps, or 'blueprints', of natural gas's possible relational arrangements are developed through the recording and aggregating of various forms of materially-mediated encounter. It is then through the consultation of these (inevitably incomplete) blueprints that I argue that attempts are made to anticipate certain kinds of gaseous phenomena, and that efforts are taken to facilitate, cancel out, or compensate for future scenarios.

In the chapter's fourth section, I then argue that blueprints are typically used in conjunction with a second set of mapping practices. These practices consist of attempts to produce 'snapshots' of natural gas's shifting relational constitution whilst it circulates. I describe how a vast array of sensory devices have come to be deployed across the UK gas networks to produce certain kinds of relational snapshot. By identifying how gas's relations are arranged at a particular moment in time, and by comparing these formations to blueprints of its known possible relations, I suggest attempts are made to pre-empt the formation of particular gaseous phenomena, and to respond to them whilst in the midst of their emergent becoming.

In this section, I also describe how efforts have been taken to greatly expand the forms of action that are able to be conducted upon gas by improving the visualizations that are produced by these sensors (namely, by enhancing the accuracy, reliability and speed with which snapshots are created). Importantly, individual sensors are shown to not produce comprehensive or coherent visualizations of gas's ontological composition, but instead capture information on particular facets, or qualities, of the gas whilst it moves. For many forms of securing action to be taken however, gas's ontological configuration needs to be visualized more holistically, and the associations between these various facets often need to be rendered known. I thus describe how many of the sensors used within UK gas networks have been carefully arranged to form a kind of reflective apparatus through which gas's material qualities at various points in space and time are transmitted back to centralized points and are assembled into more-or-less coherent forms.

Central to each of these arguments is how security's practices of rendering gas as actionable operate upon a moving, incoherent target. I argue that, whilst current governance practices may be more-or-less effective, gas has always, and *will always*, exceed the abilities of humans to comprehensively 'know' and control it, and that any account of its various formations will always be necessarily provisional and incomplete – due to the way that security's knowledge practices are situated within a world that is in the midst of its emergent becoming (Barad, 2007). In this way, I seek to destabilise the coherence of natural gas as a secured 'object', and in doing so, I seek to address some of the criticisms that I levelled earlier against the energy security and critical security studies literatures (namely, that the elements described within these literatures have typically featured in ways that render them dematerialised, unchanging and passive). In contrast, the practices described in this chapter highlight the dynamism of the gas in circulation, and draw attention to the way that this dynamism necessitates forms of knowledge production that are constantly performed across the full extent of gas's circulatory journeys.

II. Affective Incoherence[64]

In order to examine the difficulties that natural gas's material qualities present for systematically rendering it actionable, it is helpful to first consider human encounters with it prior to the systematic application of gaseous knowledge practices. I therefore begin this section with a description of a number of historic encounters with natural gas, and through these anecdotes, explore some of the ways in which gas is similar to other kinds of material, whilst at the same time showing how it demonstrates a number of peculiar qualities. These material peculiarities are then discussed in relation to the problems they present for knowing natural gas and for taking action upon it.

In the 1300s, natural gas appeared as an ethereal light that danced upon the waters of the river Tiber at night. The darkness of the night, the presence of

[64] In using the term 'coherence' here, I do not intend to suggest that it actually is possible for an entity to have a fundamental, coherent whole. Instead I wish to draw attention to how different materials may appear as more-or-less coherent wholes at different points in time. Following Barad (2007), the apparent coherence within human perceptive registers at any one moment is considered to be a contingent relational effect.

oxygen, and an electrical charge (likely caused by lightning), are thought to have come together to render the presence of gas bubbling up from under the water perceptible to humans at that particular moment (Etiope, 2015). In a similar manner, from at least the 1200s, natural gas has appeared in the form of the mysterious 'eternal' flames that issued (and in places continue to issue) from the soil in Azerbaijan[65]. To form these flames, gas, oxygen and an unknown source of ignition had to come together and alert people to the gas's existence (Searight, 2000). In the 1500s, gas became humanly sensible in a different way; through its intra-action[66] with a clay vessel, charcoal, oxygen and a source of heat in the laboratory of the Flemish alchemist, Johanne Baptiste van Helmont. In this laboratory, gas was rendered momentarily perceptible as it ignited inside of the vessel and suddenly shattered it (van Helmont and van Helmont, 1662). More recently again, from the 1700s, natural gas repeatedly appeared in British coal mines – miner's bodies, candles, oxygen from the earth's surface, and the cracked walls of the mine workings becoming arranged in ways that led to the gas expressing itself violently upon the miners' bodies (Galloway, 1882). In a similar way, William Hart's observation in 1821 of a strange effervescence on the waters of a creek in Fredonia, New York (the event commonly associated with the birth of the American natural gas industry), was only made possible through the collective intra-actions of natural gas, sunlight and water, which together pressed upon Hart's vision in that specific moment (Speight, 2007). As such, like most other materials, natural gas historically only became humanly known and actionable through its intra-actions with other heterogeneous elements.

[65] The name 'Azerbaijan' literally means "Land of Fire" (Etiope, 2015).

[66] The term 'intra-action' used here is borrowed from the work of Karen Barad (2007). It is used to make strange the common notion of causality in which one or more completed wholes interact with one another to produce an effect, and instead emphasizes the way that these elements are themselves constructed, or materialized, through these productive encounters. As such, "'individuals' only exist within phenomena (particular materialized/materializing relations) in their ongoing iteratively intra-active reconfiguring" (Barad, in Kleinman, 2013; 77).

Today, natural gas becomes present to human senses in similar entangled ways. For most people, it enters their fields of perception through its collective intra-action with the dials on gas meters and domestic appliances, or through its relations with other infrastructural elements, such as the monolithic visual presence of transnational pipelines, or in the work of the engineering teams that repair gas distribution networks. It may also appear more vicariously, such as through YouTube videos of its combustion as it is released from gas-infused drinking water[67]. Even in cases that seemingly involve direct gas-human encounters (such as when a stove is lit, or when gas is smelled in the street), these experiences are similarly facilitated through material mediations, the gas either intra-acting with the stove's burners and a source of oxygen, or collaborating with the artificial odorants that are infused within it to enable it to be smelled[68]. Whilst natural gas therefore exceeds somatic perception in its isolation, it can become affective and humanly knowable through specific forms of intra-action with other heterogeneous actants. As such, it must always be experienced vicariously, in a distanced and mediated manner. In this sense, it is thus similar to Bennett's (2009) materials, for through its intra-action with other elements, it develops 'thing power' – a collective force that draws bodies into engagement with it.

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[67] I refer here to a series of videos that have been uploaded by members of the public and consumer rights advocates that have helped to generate controversy around contemporary practices of 'fracking' in the United States. In these videos, natural gas is claimed to have entered local water supplies, with water being shown to have become flammable in the process. See for example: Gas Drilling Awareness Association (2011) https://www.youtube.com/watch?v=4LBjSXWQRV8

[68] This example of smell highlights an important aspect of the affective capabilities of materials – affects do not have to be limited to visual registers, nor do they have to be limited to physical sensations. A case in point is the way that fear is employed as a specific security device in gas's governance. Through the enrolment of discursive materials such as posters, leaflets, television advertisements, and even scratch and sniff cards (see Appendix D), concerted efforts have been made by network operators and gas supply companies to cognitively link the smell of gas to a series of risks that they seek to publicly associate with the smell of gas. The motive for these practices involves how fear is believed to translate into particular forms of public action – specifically here, an increase in the number of reports of gas escapes, an increase in the speed with which these leaks are reported, and an increase in the urgency with which people evacuate potentially unsafe atmospheres.

In order to understand how natural gas becomes perceptible to humans through these entanglements however, and in order to understand how people have come to be able to take action upon it, we need to further recognise how experiences of gas's affects depend upon the ontological constitution of the human bodies involved, and on the capacities of these bodies to be affected by the gas in different ways (Anderson, 2014). Human bodies have a limited range of senses through which natural gas can develop forms of affective contact with them, and all bodies differ in terms of these affectivities. Certain bodies may completely lack particular sensory capacities, whilst others will differ in terms of their sensitivity to particular kinds of contact[69]. Each body's affectivity will also be conditioned by their different relational contexts. As Barad (2007) usefully summarises, bodies "do not simply take their places in the world [but] are intra-actively co-constituted" (Barad 2007; 170). Had Bennett (2009) not previously encountered the works of Thoreau and Merleau-Ponty for example, and had she not been thinking about them whilst she was walking, she may not have been struck by the singularity of her litter assemblage. In much the same way, gaseous encounters are conditioned by the knowledges, experiences and relational contexts of the bodies that become involved in these encounters. A child may not recognise the smell of gas and know the risks that its presence entails, but in contrast to the child, an adult may experience alarm upon smelling it, due to their encounters with gas in the past. Bodies must therefore be understood as being always in the process of becoming; like gas, they are produced through their entanglements within the world, and gas's intelligible affects can only be understood through attending to these entanglements.

[69] Such distinctions are never fixed either, and different bodies may experience heightened or dulled affectivities at different moments in time.

What is particularly significant about this differential and contingent affectivity when considering the ways that natural gas is rendered actionable in contemporary security practices however, is that it forces us to acknowledge that the elements being secured may have qualities and affects that not only go unobserved or unrecognised at a particular moment in space and time, but which might totally exceed human intelligibility altogether. As Graham Harman has extensively argued, we consequently need to reject assumptions of "any privilege of human access to the world" (2007; 189), and instead recognise that large parts of the universe may remain entirely closed off to our limited affective experience. Each affective encounter is partial, situated, and context sensitive, and no objects, bodies, or things can ever encounter one another in their entirety. Instead, they always make contact vicariously through their relations with others, touching only obliquely at particular points. As such, "things as encountered in relation, are always a kind of distortion" (Harman, 2011; 37). What is perceived by one entity, with its specific affectivities in a given moment, is always an incomplete picture. We can therefore only ever know of gas through our bodily-subjective, and materially-mediated, affective encounters with it, and whilst efforts may be taken to "assemble different apparatuses for satisfying particular knowledge projects" (Barad, 2007; 171), the various visualizations of gaseous matter that are produced will always be provisional and will never be objectively complete. We must therefore recognise that knowledge practices, and our ability to know security's objects, are situated within the wider material configurations of the world in its intra-active becoming, and that what can be known and rendered actionable within a given moment is not exclusively defined by human intent. Gas's intelligibility, and our ability to take action upon it, is thus part of "an ontological performance of the world in its ongoing articulation" (Ibid; 149).

The corollary of this for gaseous security practices is that it means that any effort to render gas humanly intelligible and actionable must be regarded as being necessarily provisional and incomplete. Not only can we never entirely know gas and the possible roles that it could play in future phenomena, but due to the becoming nature of the world, 'matter' "is phenomena in their ongoing materialization" (Barad, 2007; 151). As gas moves through space and time, it will develop new forms of association and new ways of intra-acting, and in the process, new gaseous phenomena will become intelligible to human perception. Security's knowledge practices are thus forced to visualize a moving target, and that which is known as 'gas' is consequently never stable.

What arguably makes natural gas so particularly difficult to render known and actionable, however, is the specificity of the associations that are required for it to form in order for it to become humanly intelligible, and the rarity with which these associations naturally come together. Indeed, these requirements have typically resulted in natural gas appearing to human senses in a very different manner to Bennett's bottle cap, dead rat and black plastic glove. To a greater or lesser extent, these elements all hold their shape within human affective registers with a certain degree of spatial-temporal consistency[70]. In contrast however, natural gas is incoherent and unstable. It requires the formation of highly specific, and often fragile, sets of relations in order for it to become present to human senses, and this has often resulted in it making only very brief, infrequent, appearances within human affective registers: it danced fleetingly upon the waters of the Tiber in pre-Roman periods (Etiope, 2015). It appeared momentarily as it unexpectedly shattered van Helmont's scientific apparatuses in the 1600s (van Helmont and van Helmont, 1662). It detonated suddenly, without warning, in 18th century British coal mine workings

[70] The dead rat, which is prone to more rapid decay, may hold its shape to a lesser extent than the glove and the bottle cap, but for each of these objects there is a degree of coherence and durability in their becoming intelligible.

(Galloway, 1882; Fynes, 1873). It appeared in bubbles on an American creek in the late 1800s (Speight, 2007). Put simply, the specificity and rarity of the relations needed to render natural gas humanly intelligible has meant that encounters with it have been historically evanescent, infrequent, and geographically dislocated.

Indeed, such qualities presented significant impediments to the construction of gaseous knowledges and to its governance and commercialization. One such impediment regarded how the substantial physical distance between gas's humanly affective events meant that, like Tim Ingold's (2011; 127) wayfarer (the distance between whose eyes and feet prevented him from acquiring a panoramic vantage point of the footprints that he had left in the sand), witnessing gas's affects and reviewing them in relation to one another, was often impossible. Gas was encountered inconsistently across different countries and continents, and as such, it was always experienced in ways that were at once too close up, and at the same time, too far away.

The length of time between gaseous encounters also limited how much about gas could be known, and what forms of action could therefore be conducted upon it. The rarity with which the relations that were required for humans to perceive it formed meant that gaseous encounters were typically infrequent, and extensive experience of gas in a single lifetime was therefore very unusual[71]. As such, gas's affects were similarly experienced in ways that were typically experienced at once too close up temporally, and at the same time,

[71] It was only from the 1600s, as coal mines started to get deeper and gas could not so easily escape, that natural gas started to become more frequently and consistently encountered (Galloway, 1882). Indeed, the specificity of the relations needed to form in order for gas to be rendered visible served as a particular impediment for the development of scientific gaseous knowledges, for even when it was thought to be present, its affects could not be separated from those of other gaseous materials. As Brock (2012) records, "in the absence of any suitable apparatus to collect and study such aerial emissions, it was impossible to distinguish between them chemically" (p.52).

too far away, for knowledges to be developed regarding the conditions of its emergence, and its relations to particular phenomena. Without these knowledges, the forms of action that could be undertaken upon it were severely limited.

Furthermore, even in encounters that, on first glance, may appear to possess a greater degree of spatial-temporal consistency (as in the case of eternal flames), there was always an ephemeral quality to the gaseous encounter. The flame that heralded the presence of gas also consumed it: oxygen, methane and heat collided, and at that exact moment of revelation, natural gas would disappear from view, something new taking its place. Indeed, this is a key feature of gas-human contacts: natural gas typically becomes intelligible in the moment of its withdrawal or transformation – there is always a distance between gas's presence and the gaseous affects that are registered, interpreted and acted upon. As such, gas rarely leaves people with anything other than traces of its past[72]. It is a material that, as soon as it is encountered, has always already eluded human perception and control.

In the following sections I describe the specialized knowledge practices and 'reflective apparatus' that has been developed in response to these troublesome qualities in order to render gas knowable and actionable within contemporary performances of gaseous security. To take action upon gas and to systematically facilitate, cancel out, or compensate for, particular forms of gaseous phenomena, I argue that these strategies have had to be specifically designed to enhance gas's spatio-temporal coherence within human affective registers.

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[72] These traces are not fragments. A fragment is spatio-temporally coherent; a solid shard of a previous whole that can be held, turned over, contained, controlled – governed. Whilst both traces and fragments can have affects and speak of a dismantled whole that cannot be fully reconstructed, the trace is unique in that it recalls a phenomenon from the past and that has already eluded control.

III. Blueprints

Central to overcoming gas's affective inconsistency and rendering it actionable, is I suggest, the production of particular kinds of gaseous trace. Historically, knowledges of gas as an element have developed out of the creation of traces that could persist over time and space, and that could thus be encountered with a greater degree of spatio-temporal coherence. Like Barad's (2007) description of Stern and Gerlach's experiment, in which the movement of silver atoms became semi-solidly etched onto glass (a relational association that allowed evidence of this phenomena to travel beyond the confines of the laboratory and to be experienced by others), so the behaviour of gas came to be imprinted in a more durable way upon other materials[73]. Whilst the gas may have immediately left exceptionally ephemeral traces – a bubble on the water, the shattering of a container, a sudden flash of light and a muffled roar – the affective intensity with which these entanglements expressed themselves was so strong that they formed particular kinds of relation with other materials that helped to extend the life of the ephemeral trace[74]. Such expressions included (but are certainly not limited to) the pagan shrine that was dedicated to the lights observed from the shore of the Tiber (Etiope, 2015); the letter written by Marco Polo in which he documented his

[73] We might think of such traces as translating gaseous encounters into 'immutable mobiles' (Latour, 1986); objects that could hold their form with a greater or lesser consistency, not just across time, but also across space. It was through this relative immutability that gas's affects overcame the tyranny of spatio-temporal distance and could be vicariously experienced far away from the initial sites of encounter in a more-or-less coherent manner.

[74] Here, I consider the intensity of natural gas's affects in particular encounters to have been key to its initial formation as an object. Humanly-experienced gaseous entanglements typically tend to express themselves upon human bodies with a greater affective intensity (with greater 'thing power') than bottle caps, dead rats, and discarded plastic gloves. Bubbles, flames and explosions expressed a peculiar affective intensity that not only drew people into engagement with them, but which also consistently compelled them to record their encounters in writing, artwork, and architecture. Bennett's materials undoubtedly continue to have reverberations (indeed, I am writing about them now), but the intensity of natural gas's affects, and the way in which it leaves a wake of lingering traces, has been key to its stabilisation as an object, and to its eventual commercialisation and governance.

encounters with the eternal flames in Azerbaijan (Etiope, 2015); and the newspaper articles, investigation reports, parish death registers, and miners' memoirs that evidenced UK mine gas explosions in the 1700s and 1800s (Fynes, 1873). Such material expressions are themselves further vicarious traces of gaseous encounters, and as these secondary and tertiary traces travelled through space and time, each of these were encountered by additional bodies and things, with further traces being produced as a result. In this way, gas's reverberations came to be increasingly amplified, its affects becoming experienced across time and across space with a greater degree of spatio-temporal consistency.

In attempting to render gas actionable, the production of more durable gaseous traces became systematic. Numerous knowledge projects were conducted, and continue to be conducted – from the chemical experiments of Lavoisier in the 1700s, to the pipeline tests conducted by British Gas[75] in the 1960's. Within these projects, various actors have attempted to produce and record particular kinds of gaseous trace, adding their findings to a widening corpus of gaseous knowledge.

Initially, these knowledge projects[76] typically entailed exploring the conditions under which gaseous affects could be produced (as can be seen in the work of early chemists such as Johan Baptiste van Helmont, Robert Boyle, Joseph Priestley, and Antoine Lavoisier), but later they began to explore the ways that gas intra-acted with an increasingly broad range of bodies, materials and things. Common to all of these efforts, however, was the objective of breaking down, and making known, the ontological structure of gas, and the possible

[75] British Gas, as it is referred to in this thesis, was the organization responsible for installing and operating the NTS, prior to the privatization of the gas industry in the 1980's. The role of NTS operator is now overseen by National Grid.
[76] Bensaude-Vincent and Stengers (1996) describe knowledge projects as the process through which materials become enriched with information, resulting in the production of (increasingly) 'informed materials'.

relations that this gas could form with other elements in order to produce particular effects. By mapping these relations, attempts could be made to identify specific forms of gaseous phenomena that could possibly actualize, and action could then be taken in the present to facilitate, compensate for, or cancel out, certain kinds of gaseous event.

I suggest that we might best understand these knowledge practices, and the ways in which they operate, through the application of DeLanda's (2013, following Deleuze), concept of 'possibility spaces'. To explain what DeLanda means by the term 'possibility space' however, I now briefly turn to discuss how he sees elements (bodies, objects, things) to be ontologically constituted.

Relations of Interiority/Exteriority

For DeLanda (2006), elements and their agency arise from the specific configuration of their internalised relations (their '*relations of interiority*') and their relationships with other external entities (their '*relations of exteriority*')[77]. Relations of interiority describe the interactions between an entity's constitutive parts, and it is through these interactions that its irreducible properties can be understood to emerge. It is, for example, through the configuration of natural gas's individual molecules, in particular the specific number and arrangement of the hydrogen and carbon atoms contained within it and their relation to one another, that it becomes energetic, that it develops the abilities to combust, and amongst other actions, comes to produce heat and light.

[77] This distinction is somewhat artificial. The performance of such 'agential cuts' must, according to Karen Barad (2007), be viewed as being contingent – what is humanly intelligible is performed by the world in its becoming. The distinction between what relations are 'inside' and 'outside' the object is therefore one of aesthetics, and is employed here as a conceptual tool to help visualize security's practice.

Crucially however, the internal relations of an entity do not "explain the relations which constitute [its] whole" (DeLanda 2006; 11). Instead, an entity's ability to act in different ways is further dependent upon its relations of exteriority. Entities may possess myriad ways of acting that remain latent, or virtual, until specific relationships with other external entities are formed. Such a notion is encapsulated in the image of the fire triangle (figure 3), for whilst natural gas's relationships of interiority can be seen to provide it with the latent capacity to combust, it requires the presence of two external agents, oxygen and a source of heat, for it to ignite. Until such relations of exteriority become actualised therefore, its capacities to burn, to emit heat and light, will remain dormant, or virtual.

Figure 3 - Diagram of the 'fire triangle'

Above this first layer of actions (burning, heating, lighting), endless layers of other virtuals can be understood to proliferate. As Michel Cassé writes, "every virtual particle surrounds itself with a virtual cosmos and each in turn does likewise indefinitely" (1993; 72-73, cited by Deleuze and Parnet, 2006; 112). The bourgeoning of this constellation of virtual relations thus opens out a cloud of potential futures that are yet to be actualised. As such, whilst natural gas may burn should its virtual relations with oxygen and heat become actualised, other latent capacities can be understood to unfold beyond the fringes of these relations. A simple example of this can be seen in the opening out of gas's capacities beyond combustion to its latent ability to take life. In order for this agency to be realised, not only do exterior relations with oxygen and heat have to be actualised, but a proximate living body must also be available for the gas to form external relations with.

Virtual constellations are more complex than this simple example suggests however. Some virtuals may never be actualised, some may be entirely beyond the plane of human perception, and beyond each successive layer of virtuals there will always lay a potentially infinite number of further virtual relations. Significantly for this thesis, additional complexity arises from both the internal and external relations of entities being able to shift as they move through space and time, leading to transformations in their ontological constitution and their agency. Internal changes may occur through the inclusion or exclusion of internal components (such as in the case of natural gas flows acquiring rust particulates as they flow through corroding pipes, or gas having its hydrogen sulphide molecules removed in processing terminals), or through alterations in the relationships between these constitutive parts, as for example, in shifts in distance between gas molecules and changes in the way their atoms vibrate. Such relational shifts are significant for the governance of circulating entities, for they can affect their irreducible properties and the constellation of virtuals that surround them. In this way, new capacities and potential futures are opened up.

Blueprints & Possibility Spaces

DeLanda uses the term 'possibility space' as a spatial metaphor for these rhizomatic clouds of actual and possible relations (DeLanda, 2013). A possibility space is effectively the field of virtual relations that surrounds a particular element. Within this field resides a plethora of known and unknown forms of association and phenomena that may present various opportunities and existential threats for security, and because what is unknown is regarded as constituting the 'ultimate danger' (Dillon, 2003)[78], I want to suggest here that it is the possibility spaces of circulating elements that have become the central focus of security's knowledge practices. Security involves attempts to map out entities' actual and possible relational formations in advance, and requires efforts to identify all of the forms of phenomenal agency that may develop through these different configurations of gaseous associations. By identifying particular phenomenal formations, action can then be taken upon the relations of elements in order to facilitate, cancel out, or compensate for different phenomena, prior to their emergence.

I want to suggest that security actors visualize gas's fields of virtual relations through the construction of what might be thought of as 'relational blueprints'. The blueprint serves as a metaphor here to illustrate how more-or-less stable maps are produced of gas's spaces of possibility. These blueprints are then used as points of reference against which different kinds of relational manipulation – different kinds of securing action – can be considered and deployed. These maps are not literal blueprints. They do not necessarily take the form of diagrammatic representations of gas's possible associations (indeed, they often take the form of texts such as scientific papers, industry standards and government legislation), and their usage is not intended to suggest that gas's relations can be completely mapped out and translated into totally stabilized forms[79].

I now turn to discuss a variety of practices that have been deployed to produce these blueprints, and describe how these different texts work to render gas

[78] Dillon is writing specifically about the performance of security in relation to forms of life here, but I believe that the same principle applies to material elements that become the focus of security's practices of knowing and rendering actionable.
[79] Crucially, such blueprints are *more-or-less stable*. Whilst they have a degree of durability, their structure is not fixed, and they are in a perpetual state of being drawn.

more spatio-temporally coherent in ways that make possible different forms of securing action.

Making Blueprints (1): Experiments

Experiments are one of the most common knowledge practices through which gas's spaces of possibility have been charted to date. Typically, these experiments involve holding an object of concern (in this case, gas) within a specialized apparatus whilst an investigator forces it to make a series of contacts with other elements. The purpose of these experiments is to force the gas to affect the different elements being introduced to it in ways that are humanly intelligible. In premise, this is a little like installing a wing mirror on a motorbike. Whilst the driver may not be able to see what is behind them without the wing mirror (due to the positioning of their body within the bike-road-body assemblage), the wing mirror enables them to vicariously encounter the road behind them in a mediated manner. Similarly, by bringing gas into contact with other elements upon which it has somatically perceptible affects, different facets of its ontological constitution can be vicariously experienced.

These experiments have typically involved attempts to multiply the intra-actions that develop between the gas and the other elements that it is introduced to. Extending the motorcycle analogy, a useful image for visualizing this kind of practice is the Mod's pimped up Vesper (see figure 4). By multiplying the number of reflective devices that are deployed to vicariously encounter the gas, more facets of its ontological formation can be brought into view. Whilst it is still impossible to experience an object in its entirety (and indeed we would never know if we had), investigations are thus able to expand the field of human perception by multiplying the kinds of vicarious contacts that are made with the object of enquiry. In this way, experiments provide a means of mapping out gas's spaces of possibility by "perform[ing] causal interventions into [gas's] beings and becomings in order to discover what [its] capacities are" (DeLanda, 2013, p. 92) and also how they develop.

Figure 4 - Photograph of a Mod's Vesper

By observing these affects, attempts are then typically made to map out the lines of causality that resulted in their production. This usually involves the application of scientific reason, in which elements are combined under test conditions, in ways that isolate individual relations and enable the identification of particular causal associations. In this way, particular relational phenomena can be systematically identified, and the relations of interiority and exteriority necessary for their actualization can be catalogued.

An example of such an experimental apparatus can be seen in the tests conducted by British Gas's Engineering Research Station (ERS) during the development of the UK transmission system in the late 1960's. Amongst other agendas, the ERS was concerned with the behaviour of pressurised gas as it travelled within pipelines of different material types, particularly when subjected to a range of environmental conditions. One specific line of enquiry regarded what would happen when different types of pipeline were struck by heavy machinery. As a former engineer of the ERS recalled;

"there were lots of tests […] using diggers, hitting pipes […]. The distances that you see [in the industry standards] …you have got safe distances for all sorts of [pipeline type] …they came about initially from full scale tests. Blow it up and see how far stuff went!" (Interview with former ERS engineer, 2015)

What is being described here is a series of experiments through which natural gas was made to intra-act with different pipe materials and industrial appliances. Numerous traces were produced and recorded through the conduct of these experiments (including projectile travel distances, temperature readings, and photographs of damage to pipework and of gas cloud dimensions), and in analysing these traces, different gaseous phenomena could be identified and the lines of contingency that led to them could be mapped out. Typically, these lines were mapped using 'event trees' such as the one in figure 5, below.

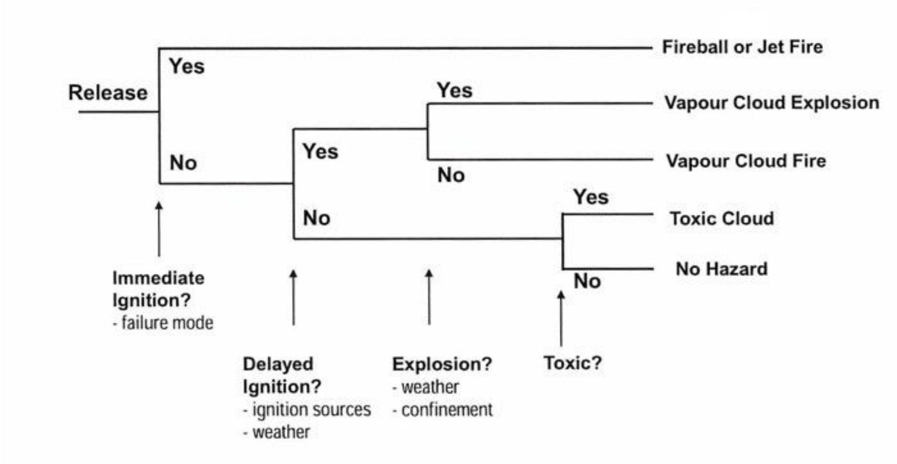

Figure 5 - Diagram of a gas escape 'event tree' (C-FER Technologies, 2014)

Efforts were then taken to avoid or compensate for particular future scenarios by altering gas's relational associations in the present. In this instance, the blueprints that were produced through these experiments helped to inform the UK's pipeline industry standards (IGEM, 1995). Specifically, they helped to identify the spatial extents of different kinds of possible gaseous affects (including jet fires, vapour cloud fires and vapour cloud explosions), and this information enabled a series of recommendations to be developed as to how far away from pipelines different kinds of property should be built (see figure 6). By building these properties beyond the perceived spatial extents of particular gaseous affects, the phenomena of human casualties or deaths could be, if not entirely cancelled out, at least greatly reduced in likelihood.

Indeed, the term *likelihood* is important here. Not only were gas's contingent associations mapped out through these experiments, but as is demonstrated in the figure below, different kinds of phenomena, and the associations that lead to them, were assessed in terms of their likelihood, or *risk*, of being realized. In the case of these particular experiments, this risk was calculated in relation to the phenomena of the loss of a single human life. Figure 6 thus demonstrates how property developments of different types should be allocated different recommended development distances, these distances having been calculated according to the relative amount of time that individuals are likely to occupy them. The less time that a certain kind of building is occupied, the lower the chance of gas forming relations with an individual human body in the event of an escape, and therefore the lower the risk of a casualty. As such, commercial buildings, which are typically occupied for fewer hours of the day than residential properties, are typically permitted to be developed closer to pipelines. In the immediate proximity of pipelines, however, no property development is permitted to take place.

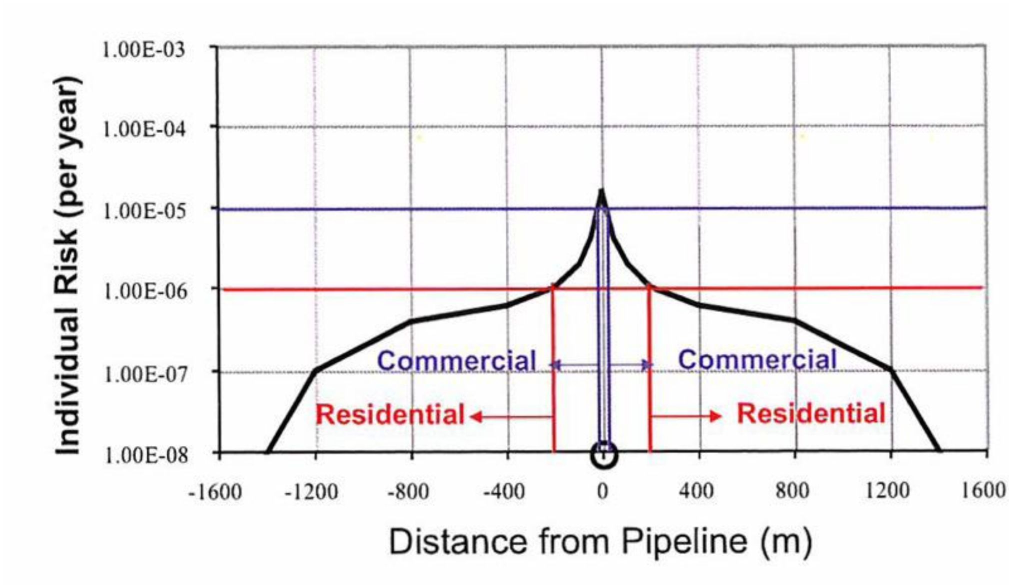

Figure 6 - Graph showing risk relative to distance from pipelines (C-FER Technologies, 2014)

As such, we can see through this example that experiments provide one means through which to render gas's possible relations known. By systematically bringing gas into contact with other elements, the lines of causality that lead to the emergence of particular gaseous phenomena can be identified, and attempts can be made to facilitate, cancel out, or compensate for, the future formation of phenomena by acting upon gas's relations in the present.

Making Blueprints (2): Investigations

A second way that blueprints of gas's possibility spaces is through the conduct of investigations following the emergence of particular gaseous phenomena. In many respects, these investigations follow a similar method to experiments, in that attempts are made to collect traces of gaseous affects, and from them, efforts are taken to establish the lines of causality that led to the emergence of particular phenomena. Typically, however, these investigations only take place after a gaseous event, typically once the gas has already departed the scene. A simple example of such a practice can be seen in the case of the investigations that follow domestic gas explosions, or other incidents that cause loss of life, casualties, or damage to property. As a former network operations director for Northern Gas Networks described to me;

"we have got to find out what the cause was. […] The thing you would first look at was what time. Usually if there is a gas explosion in a house caused by somebody and a cooker, it happens early in the morning, just as they get out of bed. Because they have left it overnight and they have got up and something has ignited. And it's bad, but you would start from there..." (Interview, former Network Operations Director, Northern Gas Networks, 2015)

What is being described here is a process of trying to map out the causal relations that led to the emergence of a particular kind of existential threat. Vicarious gaseous traces that were imprinted upon the property and its environs during the event are subsequently collected and investigated for the nature of their associations with the gas. Often the investigation of these traces extends to forensic levels of detail. During a visit to DNV-GL's Loughborough Materials and Failure Research Laboratory[80] for example, I observed the work of an engineer who was attempting to determine the causal relations behind a recent incident of carbon monoxide poisoning that had claimed the lives of an elderly couple. On his table in a sectioned-off area of the laboratory was an ageing gas heater that had been clinically dismantled, its parts removed and laid out neatly for inspection. Like an autopsy, the engineer pored over and inspected these parts in minute detail – tests were conducted, reports were written, and the cause of death was eventually pronounced. A problem with the heater's burner jets had resulted in the gas burning inefficiently, with lethal quantities of carbon monoxide having consequently been produced.

[80] DNV-GL is a corporation that specializes in research and data analysis within the UK gas industry.

The purpose of investigations such as these is both to allocate responsibility and to ascertain previously unidentified associations that may lead to certain kinds of undesirable phenomena. Attempts can then accordingly be taken to cancel out or compensate for similar scenarios in the future. A case in point is the explosion in Putney with which this thesis opened. By identifying the conditions that led to the failure of a particular component (in this case, cast iron pipes), efforts could then be taken to avoid future incidents caused by similar sets of associations forming around them. In this case, this was achieved by establishing legislation that enforced the replacement of these components.

Such investigations do not have to be conducted only around major events however. During my fieldwork, I also observed the broader collation of knowledge around more mundane escape events. As the former operations director for Northern Gas Networks explained to me;

"If there is an escape on a […] pipe, it is logged. […] It is recorded, and where it was, was it a joint, what type of joint it was, and that is going on as we speak, so that's information that is being built up" (Interview, former Networks Operations Director, Northern Gas Networks, 2015)

This form of data aggregation is conducted on an international scale. In each gas-related escape event, the pipe materials, their dimensions, locations, age, connected assets, typical operating pressures, environmental conditions (such as soil acidity, compactness, land use) and so on, are catalogued within large industry databases[81]. This information is then shared between networks, and is used to assess the risk of failures on installed pipework that possesses similar characteristics. By investigating the everyday behaviours of gas's material associations in this way, and by recording a history of these behaviours, gas companies are able to project a visualization of gas's spaces of possibility onto

[81] Site visit – RAF Spadeadam (2014).

their infrastructural environments and take particular forms of pre-emptive action upon pipework that is considered to present higher levels of risk.

From these various examples, whether they follow major events, or are conducted around aspects of the everyday functions of gas networks, investigations can therefore be seen to provide another means through which attempts are made to collect gaseous traces and to establish the causal connections between the gas's associated elements that lead to particular kinds of phenomena. By again visualizing gas's spaces of possibility in this way, action can be taken to facilitate, cancel out, or compensate for, particular kinds of future gaseous phenomena in advance of their emergence.

Making Blueprints (3): Simulations

A third way that attempts were observed to be made to map out gas's spaces of possibility was through practices of simulation. There are two ways in which simulation was observed in this study; computer modelling and live rehearsals. Simulation typically involves the adoption of a hypothetical scenario, and from this, attempts are then made to map out the gaseous associations that are likely to develop. Computer simulations work by taking a series of given parameters (gas pressures, volumes, chemical composition, affected regions) and by charting the relations that could form within them, based upon existing knowledge of gas's behaviours. As a result of these assumptions, computer simulations are useful for identifying possible links between various known elements in an emergent event, but are less adept at identifying elements that may become involved in phenomena but that have not been previously identified. A typical computer simulation can be seen in the following example described by a health, safety and environment manager at Northern Gas Networks;

"I wanted a model. We actually modelled self-isolating distribution. I found we had a single pipeline feeding [confidential], and we have a single pipeline running up [confidential] in [confidential]. So I put a couple of scenarios together, whereby someone damaged that pipeline, pressure decayed, we lose…I think it was 12000 customers in [confidential], and I think it was like 7000 customers in [confidential], mainly to get participants to escalate the incident and say we need self-isolation and restoration – we need to consider it. Run the risk assessment, and then ask our directors for their permission to take it further" (Interview, Health, Safety and Environment Manager, Northern Gas Networks, 2015)

In this example, computer simulation was used to map out the contingent spread of gaseous affects from a single hypothetical incident (accidental damage to a pipeline caused by an excavation company). To simulate these affects, a number of known or anticipated parameters were established, including pipeline design, gas pressures, weather conditions, and consumer demand, and gas's likely behaviour was modelled according to these conditions. In this scenario, the simulation predicted that gas would be prevented from reaching around 19000 consumers connected to the North of England gas distribution network. The scale of this incident is particularly significant, due to the way that network operators are currently required to attend every property that is affected by an outage to ensure that the appliances of affected consumers are shut off prior to supply being returned. If a company was not to take this action, users who had left their appliances on after the interruption to supply would find their properties filling up with gas following the return of the gas supply. Unsurprisingly, this could result in domestic explosions.

In an incident that exceeds 5000 properties however, supervising consumers' reconnection to the gas network can be an extremely time consuming and resource-intensive endeavour, and one that is likely beyond the capabilities of a single distribution company to manage quickly. As such, any outage that affects in excess of 5000 properties is currently regarded as constituting a major incident – a classification that qualifies the distribution company to receive support from other gas networks. Even with this support however, the duration of an outage can still reach into weeks and months, and in a case where such an outage occurs over winter, there is also a risk that elderly or vulnerable people will perish from the cold[82]. As a consequence, there is currently an ongoing debate in the UK gas industry as to whether the number of deaths that would be incurred from explosions (if consumers were given responsibility for managing their own isolation and supply restoration), would exceed the number of deaths that would be incurred from the cold, if they were not. It is within this debate that the simulation described above was situated. The health, safety and environment manager wanted to use computational simulations to identify potential phenomena (death from cold) and to use the identification of this phenomena to trigger a conversation around possibly altering the way that action is taken upon gas in the event of future supply interruptions.

As such, simulation can be seen to involve attempts to calculate and project lines of contingency from a set of known parameters, with the objective of assessing the risk of these relations becoming actualized. From this, an attempt is then made to assess the necessity of re-ordering the way that gas's relations are arranged in order to address certain forms of threat. Whilst, in this case, these simulation practices cannot be seen to involve attempts to completely cancel out all kinds of threatening phenomena (the health, safety and environment manager recognized that risks to consumers cannot be totally

[82] In most gas outages, distribution companies will provide consumers with electric heaters for the duration of the supply interruption. In an incident of this scale however, electricity networks are expected to not be able to cope with such large unexpected increases in electricity demand.

avoided), we can observe attempts to minimise the likelihood of casualties being incurred, and to reduce the number of people negatively affected.

The second way that simulation was observed to be employed in practices of rendering gas actionable was through the conduct of live rehearsals. Live rehearsals operate in a similar manner to computer simulations, in that hypothetical events are established, and a set of known elements and behaviours are identified. From these, attempts are then made to work out what possible relations gas will subsequently develop. Live rehearsals differ from computational simulations however, in that, rather than relying on assumptions of how elements will act in a given scenario, rehearsals involve the observation of the actual emergent behaviour of incorporated elements. Unanticipated forms of action, association, and resultant phenomena may consequently emerge and become intelligible through the conduct of these rehearsals. Indeed, these features have considerable value, for as a contingency planning officer from Durham Constabulary described to me regarding a recent rehearsal that had been conducted between 'category one' responders[83] in Durham's Local Resilience Forum, rehearsals can help to answer a series of questions.

"Do people understand [the emergency plan]? Do they know where it is actually accessible? Do they know that it is there? Because we have a lot of documents, but do people actually know that they are there to help them? So there is a lot of these

[83] The UK's Civil Contingencies Act (2004) splits the actors involved with the management of incidents are split into two groups. Category one responders are those actors that are directly involved with the management of an incident. These principally consist of 'blue light' services (police, ambulance, and fire services). They typically also involve the local planning authority for that area. In the case of a major gas escape where loss of life had occurred, or where severe risk was presented to human life, category one responders would be responsible for managing the incident. Category two responders consist of relevant co-operating organizations that may be called upon to assist with dealing with an incident. The relevance of category two responders depends upon the nature of the incident. In the case of a major gas escape, local distribution companies or the transmission system operator, National Grid, may be called upon to shut off the gas to particular areas, or to reduce its pressure.

learning points that need to be brought to the fore" (Interview, Contingency Planning Officer, Durham Constabulary, 2014).

It is in the asking of these kinds of questions that we can most clearly see the differences between the mapping practices that are involved in live rehearsals and those found within computational forms of simulation. Such questions could not be answered through computational forms of simulation due to the way that they require a method of mapping that does not prescribe or assume the ways that elements will behave in a given moment.

It is also for these reasons that rehearsals have an additional benefit. Live rehearsals can help governing actors to identify new elements that may become involved in the formation of gaseous phenomena and to identify any alterations in gas's associations that may have taken place since the last time mapping practices had been conducted. As the police officer continued;

"We accept that it is a constant learning cycle. Things are changing all the time. People are changing, organisations are changing…companies […] pipeline distributions are changing…so we have to be on the ball all of the time. […] [We will say to them:] 'we want you to test the plans this year to see if the plans are fit for purpose'. So we would put a test together to challenge the document…to […] see if the plans actually work. The information in there, is it up to date, is it relevant, are rendezvous sites identified? Are those locations still physically there? Or has someone built a house on them?" (Interview, Contingency Planning Officer, Durham Constabulary, 2014).

In this way, live rehearsals demonstrate how gas is a material that is in a constant state of emergent becoming, and they highlight how the blueprints that are produced of gas's spaces of possibility are therefore in a constant state of flux. Rather than maps of gas's spaces of possibility ever being finalized or complete, security's actors must work to constantly update these blueprints in order to ensure that security's modes of response remain efficient and effectual. As new associations and alterations to gas's existing associations become identified and incorporated into gaseous blueprints, so these developments inform security's practice, with existing actions undergoing alteration in order for particular phenomena to continue to be secured against. Indeed, it is for this reason that rehearsal practices are regularly conducted across the gas industry. Every year, they are conducted at the scale of individual organisations, county-wide local resilience forums, and national cross-industry events[84]. As the emergency operations manager from National Grid reflected:

"[we have] had an emergency plan for the last twenty years…and we have had to do it and exercise it constantly" (Interview, Emergency Operations Manager, National Grid, 2014)

From these examples, we can therefore observe the systematic application of simulation as a means of identifying new forms of gaseous phenomena and the contingent relational formations that lead to them. Through these practices, attempts can then be made to alter the way that action is taken upon gas's relations and regulate the kinds of phenomena that may emerge in the future.

Making Blueprints (4): Speculations

The final knowledge practice through which gas's possibility spaces are mapped out regards speculation. Speculation, as defined by de Goede (2012; xx) is like other forms of possibility space mapping, in that it "refers to the constitution of a visual field, a field of possible political intervention". Yet it

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[84] See (Northern Gas Networks, 2012; National Grid, 2012a; b; Wales and West Utilities, 2012) for examples of post-rehearsal reports produced following these events.

also differs from these other practices in that it imagines "a future without historical continuity with the past" (Cooper, 2006; 119). It is more imaginative than these other practices, with security actors working to creatively visualize gaseous associations and related phenomena that could conceivably happen, but that have no historical precedent.

Table top exercises are one of the most common practices through which speculative mapping is conducted to render actionable future gaseous events. Such exercises are typically conducted by a range of practitioners, either from within single businesses, or from multiple different industry organisations and other wider institutions (such as emergency services, local authorities, and other service providers), but within all table top exercises, the purpose is to get as broad a perspective as possible by assembling people from different backgrounds and training so that a wide range of possible eventualities can be identified. Participants then attempt to brainstorm potential scenarios that may affect the operation of gas networks.

No scenario is too extreme for consideration in such practices. Indeed, at a regional gas industry conference in 2014[85], Philip Swift, the operations director for Western Power Distribution[86] explained how "you can never over-react" in speculative practices, and proceeded to describe how meteor strikes, space debris and solar flares had all been discussed in relation to the continued security of UK service provision during the table top exercises conducted by his Local Resilience Forum. As Assistant Chief Constable for Devon and Cornwall Police, Paul Netherton (another presenter at this same conference) stated; "you never expect the unexpected". Speculative practices are thus one means

[85] "Don't Panic! Emergency Planning Conference" - Bristol, 19th November, 2014. Organised by the Institute for Gas Engineers and Managers (IGEM) South West and Wales sections.

[86] Western Power Distribution is responsible for the management of four electricity distribution networks covering the south west of England, and the south and west of Wales. The presence of electricity distribution companies at a gas industry conference is indicative of the way that speculative exercises are seen to benefit from cross-industry partnerships.

through which attempts are made to anticipate and render knowable the unexpected and the unlikely.

These speculative practices do not have to involve extreme scenarios however. They can also include fairly mundane events, such as a gas escape in a residential street and the way that it might interrupt traffic or put bodies at risk. Yet whether they are extreme or mundane, all speculative practices involve attempts to trace back the layers of contingent associations that may emerge, and to identify possible risks that might arise from the events that are imagined. As the contingency planning officer for Durham Constabulary described regarding the table top exercises that are conducted by the Local Resilience Forum for County Durham;

"[We might ask:] what are the key concerns here? One would be that it is right next to the A19. Do I have to close the A19? Because if I do, the ramifications are quite serious. Also, there is a residential area directly the other side of the A19. Are you going to evacuate the area? Or are you going to tell them to stay inside and shut their doors and windows? What are the risks to those people, and what are the risks involved in actually trying to get them out en masse? To evacuate a large area like that is a massive task. Have you got the resources to do it? So we would challenge them on these types of questions. So we would ask table one, but table two would have a different viewpoint. So it's about bouncing ideas off people, and some of the might have direct experience around this thing" (Interview, Contingency Planning Officer, Durham Constabulary, 2014).

In this manner, particular scenarios therefore come to be imagined through speculative exercises, and attempts are made to map out the gaseous relations that may unfold and their possible consequences. Speculative practices thus provide another means through which a 'visual field' of gas's spaces of possibility can be mapped out, and how 'political interventions' can be conducted to facilitate, compensate for, or cancel out, particular types of possible phenomena.

Making Blueprints (5): Formalisations

To conclude this section on blueprints, I want now to briefly discuss how the outputs of these different gaseous knowledge practices become translated into various kinds of blueprint. Each of these practices (experiments, investigations, simulations, speculations) involves the lines of contingency that are established through them becoming formalised and rendered more-or-less coherent via the publication of different kinds of output. These formalisations are highly significant, for they enable gaseous knowledges to travel through both time and space, and for them to be reflected upon and consulted in different locations and at different times. In this way, gas can become intelligible and actionable in a more spatio-temporally coherent manner, action being able to be taken upon it beyond single isolated encounters[87].

For experiments, the maps produced of gas's spaces of possibility through these methods have typically become formalised within relatively durable and stable documents such as scientific publications, government legislation and industry standards[88]. In a similar manner, investigative practices have often involved the publication of incident reports[89], but they may also become incorporated into government legislation and industry standards[90]. Likewise, simulation and speculative practices may become formalised through the

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[87] A nice example of this is how the UK industry standards for the installation of gas transmission pipelines (IGEM, 1995) have subsequently been adopted by other countries and networks around the world.
[88] See, for example: (Gas Safety (Management) Regulations 1996, IGEM, 1995, The Gas Safety (Installation and Use) Regulations 1998).
[89] See, for example, the incident report produced following the explosion in Putney that was described in the introduction to this thesis (HSE, 1985).
[90] See, for example, the updates to government legislation that followed the publication of the report into the Putney explosion (HSE, 2001; HSE and OFGEM, 2011).

publication of exercise reports, but they may also later become incorporated into industry-wide contingency plans, or the contingency plans of local resilience forums, and individual organisations[91]. Like experiments and investigations, they may also potentially inform government legislation and industry standards, should their findings be considered sufficiently significant[92].

In these ways, we can therefore observe the production of multiple types of blueprint through the conduct of different gaseous knowledge practices. Each of these blueprints works to collate the findings produced through different methods and permits gas's field of possibilities to be visualized in ways that provide these gaseous associations with a degree of spatio-temporal coherence that makes them possible for governing actors to comprehend and consult. From referring to these maps, governing actors can then determine how to best take action upon gas's associations in the present in order to facilitate, cancel out, or compensate for, different kinds of possible phenomena. They may develop strategies for maximising the efficiency of gas's transport, or for altering its circulation in ways that promote social productivity, but conversely, they may also draw lines through gas's field of possible relations, delineating between those relations and phenomena that are to be considered acceptable, and those that are to be considered unacceptable. In this way, gaseous blueprints provide a means of stabilizing these knowledges, each blueprint working to systematically overcome the challenges presented by gas's affective incoherence and to render gas's possible affects coherent and actionable in a number of different ways.

[91] See, for example: (Durham County Council and Darlington Borough Council, 2012).
[92] An example of this can be seen in the attempt of the health, safety and environment manager at Northern Gas Networks to use simulations to challenge current the UK legislation that requires distribution companies to supervise the isolation of consumer appliances following an interruption to their gas supply.

Whilst the stability and spatio-temporal coherence of these blueprints is important for the way that it enables gaseous knowledges to persist, travel and be developed upon, and for different forms of action to be employed upon circulations of natural gas, we should also be cautious about over-emphasising their ontological stability. As previously described, gas is an example of "phenomena in their ongoing materialization" (Barad, 2007; 151), and it is thus perpetually dynamic. As it moves through time and space, it is continually developing new forms of association, and many of these associations may also currently exceed human capabilities to know them. As such, security has to follow a moving target. In order for phenomena to continue to be facilitated, cancelled out, or compensated for, gas's possible associations have to be mapped and remapped, and blueprints of its spaces of possibility continually redrawn[93].

IV. 'Snapshots'

It is because of gas's relational dynamism that I suggest that a second set of practices (after 'blueprints') have been developed to systematically render gas actionable within the UK's gas transport industry. These practices might be broadly described as involving attempts to produce periodic 'snapshots' of gas's ontological configurations, whilst it is in motion. These snapshots are different to blueprints in that, whilst they similarly are designed to visualise gas's field of associations, their purpose is to provide an indication of the forms of association that gas has developed at a particular moment in time. By then comparing these snapshots to blueprints of gas's spaces of possibility, I suggest that governing actors attempt to apprehend particular kinds of phenomena in the midst of their emergent becoming.

[93] The UK industry standards are illustrative of this. Currently, these standards (which were first developed in 1965) are in their fifth edition.

These relational 'snapshots' can be seen to have been collected from the very earliest days of the UK gas industry, yet over the last 200 years, the number of snapshots produced, and the forms of governing action that have been made available through their production, have proliferated. Whilst initially such snapshots were relatively few in number and were pretty inaccurate – produced through methods such as the counting of lit windows in order to calculate billing amounts, or the weighing of coal in order to assess the approximate volume of gas that would be manufactured (Schivelbusch, 1995) – today, the number of snapshots produced of gas circulations on a daily basis has increased exponentially, and has become a highly precise art. There are currently a vast number of meters and other kinds of reflective devices that are distributed across gas's circulatory paths and that work to measure the gas's various ontological facets moment-by-moment. There are sensors to measure gas flow; sensors to measure gas pressure; sensors to measure temperature; complex chromatography units that measure its chemical specification; gas detectors that detect its presence. Every property that is connected to the gas system has a domestic gas meter installed to measure the volume of gas that is consumed within that place of residence. Added to these mechanical devices, there are also millions of human noses that belong to members of the UK public that have been called upon to detect gas leaks by inserting artificial odorants into the gas. Some of these noses have even been specially trained to assess the intensity of the gas's odour[94]. Engineers will also look to record other indirect traces of gaseous phenomena, from lathering household detergent onto exposed pipes to detect the presence of gas and the location

[94] Rhinology training was also provided at DNV-GL's Flow Centre in Chilton. Rhinologists are trained to detect variances in the strength of the artificial odorants that are added to gas circulations.

of leaks, to looking for areas of faded grass that might indicate where gas is escaping from outside of properties[95]. New sensory technologies are also being continually developed, including fibre optics, within-pipe mobile camera units, and new varieties of flow meters[96].

This plethora of reflective devices has been employed to break down aspects of gas's ontological configuration at given moments in time and to provide indications of how that gas will behave in the future. Like blueprints, they thus provide a means of visualizing gas's field of possibilities, albeit within a highly specific spatio-temporal context. The vast majority of these devices (pressure sensors, temperature sensors, flow meters, and chromatography units) focus on gas's constantly-changing relations of interiority. Chromatography units, for example, provide a particularly clear illustration of the way that gas's relations of interiority are rendered knowable and actionable in near to real-time. They are installed at the entry points and off takes of the NTS, and their purpose is to break down the gas into its constitutive chemical components, thereby enabling the relative quantities of each material within the gas to be assessed. Whilst natural gas is primarily made up of methane, it typically also contains varying amounts of other gases such as oxygen, nitrogen, hydrogen, hydrogen sulphide, carbon dioxide, and carbon monoxide. It might also contain other materials in vaporous states such as higher-level alkanes (ethane, propane, butane), sulphur and water. Differences in the concentrations of each of these chemicals can dramatically change its material qualities and can introduce a range of potential opportunities and threats. Increases in hydrogen sulphide,

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[95] Data for this point came from interviews with a former emergency repair engineer for Northern Gas Networks in 2014, and with the former network operations director from Northern Gas Networks in 2015. It is additionally supported by a range of archival material, such as British Gas's (1986)guide; "A Guide to Vegetation and Tree Surveys".

[96] I encountered many of these new technologies first-hand during my visits to industry expositions (these included the expositions at the International Pipeline Conference 2014, in Calgary, Canada, and the IGEM Annual Conference 2014, in Loughborough, UK).

for instance, can make the gas highly corrosive and toxic to human bodies[97], and any change in chemical composition will also alter the gas's energy content. Changes in energy content can similarly affect consumer safety, either dramatically increasing the size of flames that are emitted from domestic appliances, or causing the gas to burn inefficiently, with poisonous carbon monoxide being produced as a result[98]. Furthermore, such alterations can affect the gas's affordability, due to the way that the price of gas that is paid by consumers is typically fixed. Energy-rich gas will cost suppliers potential revenue, whilst low energy gas will mean that consumers receive less heat than they are paying for[99].

Indeed, it is for these reasons that the Gas Safety (Management) Regulations (GS(M)R, 1996) are enforced by the UK parliament. The GS(M)R stipulate the precise chemical specifications to which all transported natural gas in the UK should adhere[100], and they state that any "person who conveys gas in a network must ensure that suitable and sufficient tests are carried out to ensure that the gas conforms with [these] requirements" (GS(M)R, 1996: 8: 5). Chromatography provides a means to conduct these tests.

Conceptually, the practice of chromatography is interesting, for through it natural gas's relations of interiority are broken down through the production of a series of traces that enable aspects of its fields of possibilities to be mapped

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[97] Hydrogen sulfide is particularly problematic if it enters gas streams due to the fact that it is not consumed when burnt. As gas is burned within domestic appliances therefore, the hydrogen sulfide contained within natural gas will simply pass through the appliance and into properties, potentially poisoning consumers (Interview, operations supervisor for St. Fergus gas processing terminal, Shell, 2015).

[98] This is because the burners on all domestic appliances are calibrated to efficiently burn a particular specification of gas - the specification typical of gas produced domestically, in the North Sea (Interview, former network operations director, Northern Gas Networks, 2015).

[99] Interview, emergency operations manager, National Grid (2014).

[100] These specifications were based on the chemical profile of gas from domestic reserves in the North Sea (Interview, operations supervisor for St. Fergus gas processing terminal, Shell, 2015).

out in relational 'snapshots'. These snapshots are then compared to blueprints of gas's known possible formations, and the phenomena that they can help bring into being. The GS(M)R constitutes one such set of blueprints. Within it, we can see gas's possible chemical associations having been already mapped out, and their various consequences assessed. Certain forms of chemical configuration have accordingly been regulated against, due to the way that they are regarded as leading to particular kinds of threatening phenomena. Yet these actions can only be employed to perform gas as secure when they are used in conjunction with the snapshots of its ongoing ontological configurations that are produced through chromatography units. Chromatography thus provides a means through which to identify the chemical associations that make up gas's relations of interiority at a particular moment in time, and can therefore enable operators to identify the potential emergence of particular forms of gaseous phenomena whilst in the process of their emergent becoming. From this comparison, action can then be taken to manipulate gas's relations so as to manage the phenomena that come into being.

Whilst the majority of the reflective devices that are employed across the UK's gas networks are concerned with visualizing gas's relations of interiority, a number of practices are employed to also map out gas's relations of exteriority at particular moments in time. A good example of this is provided by the use of portable 'Gascoseeker' gas detectors[101]. These are used by maintenance engineers to detect the presence of gas and its explosivity, typically following a gas leak. They work by sampling gaseous components in an atmosphere and assessing their relative atmospheric ratios. Not only can they identify when natural gas is present in a volumetric space (thereby enabling the spatial extent

[101] This is the most commonly used brand of gas detectors within the UK gas transport industry. Data used in this example comes from conversations with Gas Measurement Instrument Limited employees at an exposition at the IGEM annual conference, 2014, and from their company website (www.gmiuk.com).

of a gaseous volume to be assessed) but they also provide a quantitative assessment of the relationships of exteriority that exist between the methane in natural gas and the oxygen in the air.

This relationship is extremely important for gas engineers and emergency responders, for methane has become known through previous mapping exercises to become explosive when it enters into a specific kind of relationship with oxygen. In order for methane to explode, it must constitute between 5% and 15% of a given atmosphere, whilst the remainder must consist of air[102]. The Gascoseeker detector is thus designed to assess this relationship and to render it perceivable by mapping the relations between these gases via a digital dial on its LCD screen.

Gascoseeker detectors are thus employed to render certain of gas's relations of exteriority visible through the production of particular kinds of 'snapshot'. By then comparing these snapshots to stabilized gaseous knowledges, actions can be taken to apprehend particular phenomena in the midst of their emergent becoming. With the case of Gascoseekers, this may involve the evacuation of individuals from affected or nearby property. In this way, gas may be prevented from developing the relations of exteriority necessary for it to take human life. In very severe situations where the concentration of methane within a property is extremely high however (and therefore where the concentration of methane is well above its explosive limit), governing actions also may involve warning responders to not immediately open doors or windows, for fear of letting in oxygen and bringing the gas back within a range in which it could realize its explosive agency[103].

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[102] Interview, Resilience Manager, Durham and Darlington Fire and Rescue Service, 2015.
[103] Site visit, RAF Spadeadam, 2014.

In these ways, we can therefore see a series of attempts being made to produce rapid snapshots of gas's immediate relations of interiority and exteriority through the deployment of a series of reflective devices. From consulting these snapshots and comparing them to existing blueprints of gas's possible relations, attempts can also be seen to be made to facilitate, cancel out, or compensate for, particular kinds of gaseous phenomena, whilst they are in the midst of their emergent becoming.

Rendering Gas More Easily Actionable

In the developments that have taken place in practices of producing gaseous snapshots across the UK gas industry over the last 200 years, we can also observe attempts to expand the forms of action that can be taken upon circulations of natural gas by enhancing the quality of the relational snapshots that are produced. The quality of these snapshots, I suggest, can be broken down into three constitutive parts; their accuracy, reliability, and speed. The first of these – accuracy – concerns the degree of discrepancy between how gas is depicted to be circulating, and how it is actually moving at that given moment in space and time. Reducing these discrepancies, I argue, is key to effectively rendering moving gas actionable, for in order to confidently take particular forms of action upon the gas, it is necessary to know that the visualisations created of gas's associations actually reflect gas's ontological composition at that moment in time.

During my fieldwork, I witnessed numerous efforts to improve the accuracy with which gaseous traces could be produced. The clearest example of this can be seen in the meticulous attention and care that is paid to the development and maintenance of orifice meters. This type of flow meter is just one of many that are deployed across UK gas networks to track the volume of gas that is flowing through particular pipes at given moments. Their primary role is to enable gas to be rendered financially accountable, and to enable financial transactions to be conducted surrounding the circulation of natural gas.

Operationally, these meters work by enabling a comparison to be made between the pressure readings that are collected at either side of a perforated plate that is inserted into the gas stream. This perforation, or 'orifice', must possess extremely specific dimensions in order for accurate assessments of gas's flow to be produced. Even tiny alterations to its edge sharpness, bevel angle, or surface roughness can dramatically alter the amount of gas that travels through it, and this can significantly interfere with the accuracy of the snapshots that are created. To address this, orifice plates are designed to exacting specifications[104], and in recognition of the fact that they may become damaged over time and their accuracy change[105], they are typically inspected annually. Such inspections are extremely meticulous. During a visit to a DNV-GL's flow centre in Chilton, County Durham (a facility that provides meter testing, calibration and certification services), I had the opportunity to observe first-hand the thoroughness of this process.

"The engineer gingerly handled the steel disks with cotton gloves. He rested them on a perfectly flat table made of marble. The cooling properties of the marble apparently allowed the plate's heat to equalise across its surface, rendering any warping observable to the human eye. Using the flatness of the marble counter as a guide, he inspected the cooled plate for warps, searching for any indication of a change in its curvature. He then placed it under a microscope and pored over its surface at length, searching for microscopic changes in its smoothness. Eventually, he mounted the plate in a projector that cast a magnified silhouette of the plate's profile onto a technical drawing of the plate of the same scale. Against these drawings, he then compared the plate's shadow, searching for minute discrepancies that could influence

[104] European Standard, BS EN ISO 5167-2: 2003.

[105] Such changes are typically caused by debris suspended within gas flows colliding with orifice plates.

the accuracy of the meter's reading" (Extract from field notes, site visit, DNV-GL Flow Centre, 2015).

One of the reasons for employing such exacting methods is that, as the calibration engineer explained, *"in every little step there is an element of error"*. The consequence of this is that inaccuracies can thus accumulate across the entirety of the transmission and distribution systems, and such accumulation can potentially lead to the distance between gas's actual ontological configuration at a particular point in space and time and the snapshots that are produced of it, widening dramatically. As a senior engineer from National Grid who is involved with assessing fiscal metering inaccuracies on the NTS put it;

"uncertainty is often fine [in one component] …but [the gas network] is a combination of many individual components. […] Each one has its own allowed uncertainty" (Interview, Senior Engineer, National Grid, 2015)

This increasing distortion can have considerable impacts for the forms of gaseous phenomena that can emerge, and for the way that action can (or rather, cannot) be taken upon them. Even on a single meter, the consequences of inaccuracies can be enormous. Minor dents, buckling or warping in orifice plates can potentially result in millions of pounds of lost revenue[106], and when inaccuracies are added up over the whole system, the amount of revenue lost can be extremely significant. Indeed, between 2015 and 2016, a total of 2765 GWh of gas (approximately £88 million) was estimated to have gone unaccounted for (National Grid, 2016)[107]. Whilst no direct danger is presented to individuals (gas has not escaped the system), the costs *are* passed on to consumers, and this can affect the affordability of the

[106] Conversation, calibration engineer, DNV-GL Flow Centre, 2015.

[107] This represents less than 1% of total annual gas flow, but due to the vast quantity of gas transported across the UK each year, this amount remains financially significant.

gas for members of the public. Metering inaccuracies have consequently become a source of concern for the UK government's industry regulator, OFGEM (the Office of Gas and Electricity Markets), and have recently resulted in the publication of a series of incentives designed to encourage gas companies to reduce the amount of gas that goes unaccounted for (OFGEM, 2016).

The second means through which attempts are made to improve the quality of gaseous snapshots concerns their reliability. Reliability refers here to the consistency with which these sensors produce snapshots of a particular quality. Whilst a flow meter might typically produce extremely accurate readings, if it only does so for some of the time then its snapshots are much more difficult for governing actors to take action upon. In this scenario, a meter that reliably produces less accurate traces might be preferable[108]. Efforts have thus been taken to both improve the reliability with which snapshots are produced, and to provide means to assess the reliability of these devices from a distance, without gas flow being interrupted in the process[109]. Modern ultrasonic flow meters embody both of these agendas. Not only are they extremely reliable, but they also send back a range of diagnostic data to network operators alongside each snapshot that they produce. This data relates to a wide range of different aspects of meter readings (as can be seen in figure 7), and these readings can then be used to assess whether the meter is functioning correctly, and whether the snapshots produced can be relied upon to inform any subsequent actions to be taken upon the gas. This reliability is also enhanced by the analysis of the data being automated, for should the uncertainty with which these snapshots are produced exceed a certain limit, an alarm will be triggered that will alert the operator and warn them that the data transmitted is

[108] Site visit – DNV-GL Flow Centre, 2015.

[109] In order to undertake work on a pipeline and remove a meter for testing, it is often necessary to redirect gas flow (Interview, senior engineer, National Grid, 2015).

no longer reliable. As such, the operator can proceed in confidence that, unless an alarm sounds, the snapshots of gas's flow rates that are recorded by these meters are reliable and can be safely acted upon[110].

Meter Diagnostics (Paths & Transducers)

VOG [m/s]	Average	Maximum	Minimum
Path 1	29.319	29.611	29.050
Path 2	32.786	32.906	32.668
Path 3	34.081	34.207	33.942
Path 4	30.812	30.966	30.615
Average	28.346	28.410	28.270

SOS [m/s]	Average	Maximum	Minimum
Path 1	380.82	380.92	380.69
Path 2	380.64	380.71	380.57
Path 3	380.55	380.62	380.48
Path 4	380.83	380.91	380.75
Average	380.71	380.79	380.65

	AGC [dB]	SNR [dB]
Path 1 AB	47.8	28.3
Path 1 BA	46.3	34.4
Path 2 AB	51.7	24.9
Path 2 BA	52.0	25.2
Path 3 AB	50.8	24.0
Path 3 BA	50.5	28.6
Path 4 AB	48.3	29.3
Path 4 BA	47.1	32.7
Avg AB	49.7	26.6
Avg BA	49.0	30.2

	Perform. Avg [%]	Turbulence Avg [%]	Velocity Ratio	ACC Diff. AB - BA
Path 1	74	3.1	0.902	1.460
Path 2	73	1.9	1.009	-0.320
Path 3	83	1.5	1.049	0.280
Path 4	77	2.4	0.948	1.280
Average	77	2.3	0.977	0.675

Counter Readings			
Volume [m³]	Normal	Error	Total
Forward	15899102.7	697.4	15899800.5
Reverse	15838046.8	84.3	15838131.1

Figure 7 - Image of an ultrasonic flow meter's diagnostics report (SICK Ltd., 2015)

The final means through which attempts are made to improve the quality of gaseous snapshots concerns the speed with which they are produced. During my fieldwork, I observed numerous cases in which attempts had been made to reduce the amount of time between the production, delivery and interpretation of consecutive snapshots, and the moments of gas's transformation or withdrawal. Within such attempts, the goal was to create a system of reflective devices through which users could identify emergent gaseous phenomena and render gas's relations actionable quickly enough for action to be taken upon them before particular phenomena could fully actualize.

The clearest example of these kinds of attempt can again be observed in the practice of chromatography. By comparing the contemporary use of chromatography to its deployment in the governance of town gas, we can see that the speed at which snapshots of gas's chemical constitution are produced has accelerated dramatically. From these increases in speed, we can also

[110] Site visit – DNV-GL Flow Centre, 2015.

observe the emergence of a variety of new forms of possible securing action that were not available during the governance of town gas.

Like with natural gas today, chromatography in the past was used to measure the levels of harmful chemical materials that were contained within the gas, and to assess its energy content[111]. Composition was measured straight after its manufacture, and these measurements enabled network operators to alter the manufacturing process in order to produce gas that was safer and more profitable. In its early usage however, these kinds of chromatography practices were laboratory based, and involved the gas being passed through a series of scientific apparatuses to create a range of qualitative and quantitative traces. Calorific value (a measure of the gas's energy content) was assessed through the use of a calorimeter (see figure 8)[112]. Hydrogen sulphide (a toxic chemical that could harm consumers) was detected through a device that passed the gas through a glass chamber containing lead acetate sheets (if any sheets visibly blackened, hydrogen sulphide was deemed to be present - see figure 9), and a separate device was used to collect information on the carbon dioxide, carbon monoxide, and hydrogen components contained within the gas (see figure 10)[113].

[111] In the case of town gas however, the measurement of energy content was largely conducted to assess the efficiency with which gas was being manufactured. The less efficient this process, the more the gas cost the gas company to produce (Smith, 1945).
[112] This worked by recording the quantity of gas required to raise the temperature of 1kg of water by 1°C (Smith, 1945).
[113] This apparatus worked by forcing the gas to intra-act with caustic soda, oxygen and heat within separate reaction chambers (visible in figure 11). Through measuring the products of these reactions, the presence and approximate volumes of each constituent gas could be estimated.

Figure 8 - Photograph of a town gas 'calorimeter' (Fakenham Gas Museum, 2014)

Figure 9 - Photograph of the apparatus used for detecting hydrogen sulphide in town gas (Fakenham Gas Museum, 2014)

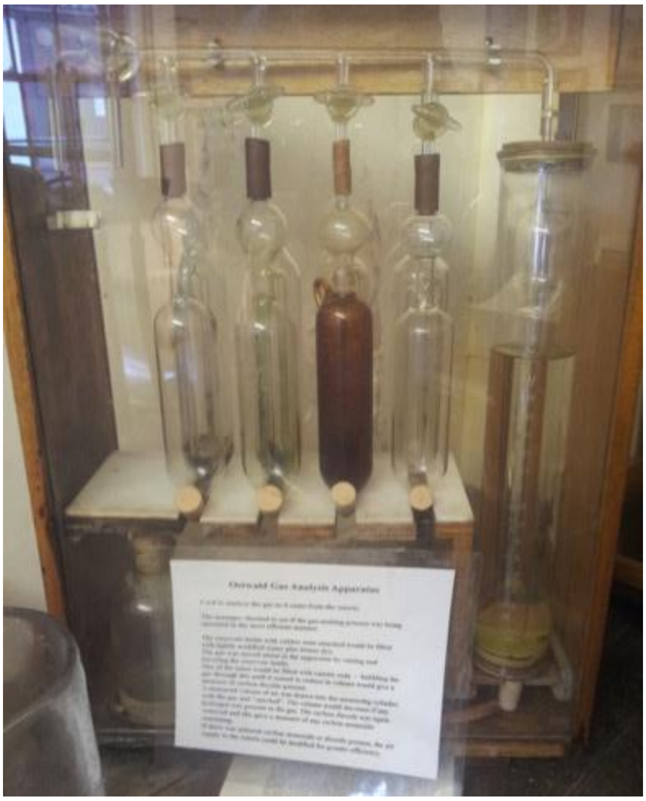

Figure 10 - Photograph of the apparatus used for analyzing the chemistry of town gas
(Fakenham Gas Museum, 2014)

These experiments took a considerable amount of time to complete – a matter exacerbated by their multiple steps often being overseen by a single operator. They were also typically only conducted periodically throughout the day, meaning that any alterations in gas's quality between these periods would evade visualization (a matter made worse by the fact that fluctuations in gas quality were very common in the production of town gas due to the imprecise nature of the gas's manufacture). Combined, these two characteristics led to production of snapshots that often did not represent gas's fields of possibilities particularly accurately, and which were also often produced too slowly to prevent sizable quantities of poor quality, and often toxic, gas from entering the distribution networks[114]. Speed was therefore significant for gas's

[114] The data drawn on here comes from a site visit to Fakenham town gas museum in 2014, and from archival research at the National Gas Archives in Warrington. Additional archival material

visualization and governance, both in terms of the time that it took to produce these snapshots, and in terms of the frequency with which snapshots could be produced.

Today, the length of time between the production of snapshots and the moment when gas actually possessed these compositions has been dramatically reduced. Automated chromatography units are fitted to the NTS at all of its entry and exit points, and through the use of attached computers, these units break the gas down into its multiple constitutive chemical components and transmit the data to network operators. Different constituent gases take slightly different amounts of time to pass through an internal column, and such differences enable their identification. A quick reading by a modern chromatography unit will now identify gas's internal structure in less than 2 minutes[115], and it will also repeatedly test the gas at very short intervals, providing rapid updates on changes in the gas's composition.

These improvements to the speed with which snapshots are produced have had considerable benefits. Whilst natural gas cannot be governed by adjusting its manufacturing process[116], it can be governed by amending the way that it is

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was sourced from the library of the National Gas Museum in Leicester, and from the library at Fakenham town gas museum.

[115] Interestingly, different chromatography units will be used for different applications. Whilst certain units will be used to produce quick snapshots of gas's chemical composition, other units will be employed to produce more accurate traces; a process that can take up to 20 minutes (Interview, senior engineer, National Grid, 2015).

[116] Whilst gas is no longer manufactured, its composition is still measured for similar reasons. As described to me during an interview with an operations supervisor at Shell's St. Fergus gas processing plant in 2015, natural gas can still contain toxic components depending upon the gas field it has been extracted from. A question of efficiency also still enters its governance. Because the price of gas that is paid by consumers is typically fixed, sudden increases in gas's energy content will mean that these consumers receive more energy for their money, at the cost of producers. Additionally, changes in gas's composition present further kinds of health risks to consumers. As described to me within my interviews with the emergency operations manager from National Grid in 2014, and with the former network operations director of Northern Gas Networks in 2015, because the gas appliances that are used by UK consumers are all calibrated to burn a certain specification of gas, fluctuations in its composition can result in dangerously exaggerated flames, or in its inefficient combustion (which could potentially

processed prior to its entry into the NTS. Off-specification gas can also be denied entry to the NTS by closing the valves that separate processing terminals from NTS entry points. Time is critical within these actions, for every minute that passes involves the inclusion of greater volumes of undesirable gas entering the system. A small amount of this gas can be tolerated, for it will simply mix with the large volume of gas that meets GS(M)R specifications that is already in the system. As the emergency operations manager at National Grid explained;

"If it does enter the NTS, then it is not the end of the world. We'll blend it. There's plenty of gas in the pipeline that's on spec, and you know, you can blend that quite easily. Which is why we have, you know, we give them say, five minutes once we have realised that's happened. You've breached, then you're off" (Interview, emergency operations manager, National Grid, 2014)

The speed with which fluctuations in gas quality can be identified and responded to is thus important in this process, for if the amount of undesirable gas entering the system can be kept within certain limits, then its threatening agency can be nullified, or cancelled out. If too much off-specification gas enters the NTS however, then the impacts of this gas could range from it poisoning consumers to it causing advanced corrosion within transmission and distribution pipes (not to mention heavy financial penalties being placed upon the network operator by OFGEM)[117]. As such, speed has become a major focus within chromatography practices, to the extent that it is not just the time that it takes to produce snapshots or the frequency with which they can be produced that has become the focus of improvement, but also the speed with which

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lead to the poisoning of consumers due to the production of carbon monoxide). The specification that these appliances were calibrated to was initially developed based on the chemical profile of natural gas as extracted from domestic gas reserves in the North Sea and, due to these potential implications, it is now legally enforced according to the UK's Gas Safety (Management) Regulations (1996).

[117] Interview, emergency operations manager, National Grid, 2015.

these visualizations can be interpreted and responded to. As the emergency operation manager continued;

"So we have rate of change alarms. So if something started to shift, away from what it was doing, that rate of change and how quickly it is changing would trigger an alarm. You will see something is happening. Then you have tiers, so […] we will pick up the phone [to speak to the gas processing terminal operator] and go 'what's happening?' Then there is a warning, 'if you don't do something about this now, you are going to be off', and then if it breaches, we will take them off. And we will tell them we're going to shut you down now" (Interview, emergency operations manager, National Grid, 2014)

What is being described here is not just an attempt to respond to rapid changes to gas's chemical composition, but also an attempt to improve the speed with which alterations in gas's relations of interiority can be identified and addressed. By sounding an alarm at the moment that these relations begin to change, operators are forced to immediately acknowledge changes in gas's composition and to accordingly undertake responsive action. As such, through improving the frequency with which traces are produced, by reducing the time that it takes to produce these traces, and by lowering the length of time between the production of these traces and the deployment of responsive action, the temporal distance between the production of these traces and the transformation of gas into new forms is reduced, and through these improvements, new kinds of political intervention have been made available, enabling emergent phenomena to be arrested in advance of their actualisation.

Along these three trajectories – accuracy, reliability, and speed – attempts have therefore been made to improve the quality of the relational snapshots that are produced of gas as it travels across UK gas transport networks. Each of these improvements to how gas's dynamic relations and fields of contingent possibilities ae visualized has also involved the opening up of new forms of possible securing action that can be taken upon circulations of natural gas.

Reflective Apparatuses

The final aspect of gas's systematic rendering actionable regards the development of a specialized reflective apparatus through which multiple snapshots of gas's ontological facets are produced and are reflected back to centralized points of interpretation. Again, the image of the bike with multiple wing mirrors is useful here, for it is through the aggregation of a multiplicity of reflective devices, their precise angling, and the careful positioning of an observer, that attempts can be seen to be made to bring more of the gas's field of possible relations into view at any one moment, and that new forms of action are made available to govern the circulation of gas. I wish to illustrate this point in the following paragraphs through a discussion of the role of the remote telemetry devices and supervisory control and data acquisition (SCADA) systems that are currently employed within the UK's gas transport networks.

Remote telemetry entails the digital transfer of snapshots of gas's relations over private data networks. This typically involves the installation of computational systems alongside the various sensors that take snapshots of gas's different ontological facets across pipeline networks. These computers then process each sensor's data and transmit it over a private data network. The data is then received and collated by network-connected SCADA systems. These systems can be contained within network control rooms, but they may also be remotely accessible via portable network-connected computers that are controlled by network operators. These SCADA systems provide a means of aggregating multiple gaseous snapshots and of assembling them in a way that visualizes gaseous traces in a more coherent manner, enabling gas's field of possibilities within a given moment in time to be more comprehensively surveyed by a single operator. Typically, this involves the translation of these snapshots into more easily interpretable forms through the application of graphical user interfaces[118].

Added to the visualization tools that are provided by these systems, they can also enable various aspects of gas transport networks to be controlled from a distance. Telemetry devices can be installed to remotely manage the functions of different assets dispersed across these networks (such as gas compressor turbines, emergency shut off valves and pressure regulators), and SCADA systems can make the control of these devices remotely available to specific users. As a result, not only have attempts been made to construct a system through which gas can be rendered knowable as it circulates, but this architecture has also been designed to enable a variety of governing actions to be performed remotely in relation to these visualizations.

The benefits of creating complex apparatuses such as these becomes apparent when we consider how gas has been historically governed in the UK transmission and distribution networks, prior to the application of such systems. As the former network operations director for Northern Gas Networks reflected in relation to previous practices of corrosion monitoring;

"if you have got mobile technology feeding back into a computer system, that analyses the data, and says well look, you don't need to worry about that 90%, but you do need to go and look at this one. Well you never had that. That's significant…one guy is now managing all of that, and that's due to mobile technology. […] There's not a lot you can do with a single reading!" (Interview, former Network Director, Northern Gas Networks, 2015)

[118] Data for this example comes from visits to national and regional network control rooms for the UK gas transport networks, and from conversations with SCADA manufacturing companies at the International Pipeline Conference in Calgary, 2014.

Here, he makes reference to how pipeline networks constitute sprawling, rhizomatic infrastructures that spread across wide geographical areas. Without a means of aggregating the snapshots that are produced across these networks, sensors have to be individually visited, interpreted and assessed. Due to their wide distribution, the manual assessment of these sensors would be a highly time-intensive task that involves very long intervals between successive checks, regardless of how frequently the sensor itself may be able to take readings. By automatically aggregating traces and reflecting them towards a central point however, gas and its associations can be made humanly intelligible in a way that overcomes their spatial and temporal incoherence. In this example, this coherence enables action to be taken upon corrosion that could not have been undertaken previously. Instead of corrosion monitoring stations having to be checked in person, and long periods of time consequently passing between sensor readings (a situation that would increase the risk of avoidable failures), corrosion on these gas systems can often now be monitored across their geographical extents quickly and with minimal effort, significantly lowering the risk of major gas escapes.

Yet there are also limits to the extent to which it is possible to effectively construct these kinds of reflective architectures. For example, the vast geographical extent of these gas networks makes assembling nation-wide reflective devices that can precisely locate and render gas escapes intelligible both a technologically and economically unfeasible endeavour. Gas could escape from any point on any pipe across these systems, and many thousands of sensors would have to be deployed to reliably reflect actionable traces of leaks back to network operators. On the NTS, this is not such an issue, for as was explained to me by the senior engineer from National Grid, the periodic measurement of gas pressure, combined with the high pressures that this gas is transported at, mean that any escape on this system will likely be large, and will therefore show up on near to real-time pressure maps (the linear design of NTS pipes means that any sudden drop in pressure will be observable through the difference between one pressure sensor's reading and the readings of the other sensors upstream or downstream from it)[119]. In distribution networks however, pipelines are more rhizomatic, and gas pressures are generally much lower. This means that locating gas leaks remotely through pressure sensors is a nearly impossible premise. The cost of installing sensors to automatically detect leaks is also unfeasibly large considering the relatively small volume of gas that passes through each individual pipe[120].

To address this, gas's governing actors have taken an alternative approach. By imbuing the natural gas with a humanly sensible affect by adding an artificial odorant, the gas is made able to affect human bodies in a more direct and consistent manner. By also educating members of the public regarding its smell and of its hazardous potential[121], an attempt has been made to incorporate the millions of human bodies that are distributed across the UK into the reflective apparatus that surrounds natural gas's circulation. Gaseous traces that are detected by these bodies are then similarly relayed to operators through a centralised gas emergency service helpline[122], and through this telephone network, reports of gas's escape can therefore be aggregated and mapped, and action can be taken upon the escaping gas.

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[119] You would expect to observe pressure decay being read by these sensors, too – otherwise the reading is likely to be due to a failure with the sensor, rather than the pipe itself (Interview, senior engineer, National Grid, 2015).

[120] As the health, safety and environment manager at Northern Gas Networks explained to me, it might be possible to observe a very big escape by consulting the pressure readings on the SCADA systems used by distribution networks, but this cannot be relied upon.

[121] Such public awareness campaigns have included television advertisements, posters, and even the distribution of 'scratch and sniff' cards, such as the one attached in Appendix D.

[122] This helpline is run by National Grid. In a gas emergency, call: +44(0)800 111 999.

Yet despite the enrolment of these human bodies, gas's escape still highlights one of the major problems with such kinds of reflective apparatus: namely that, for gas to be governed most effectively, it has to be situated within the apparatus's limited field of vision. Because reflective devices need to be carefully angled to convey their readings to a centralised point and to render natural gas more spatio-temporally coherent, they are not particularly well-suited for visualizing gas that has escaped their focal points. Indeed, once gas has left a pipe, the number of facets of its ontological structure that can be visualized, and the efficacy with which it can be rendered coherent, is severely reduced. As a result, the forms of action that can be deployed upon gas are limited. Once it escapes the pipeline network, it becomes irretrievable. It rises into the atmosphere and mixes with other gaseous materials in ways that prevent its subsequent commercialization.

Yet these limitations do not render gas completely impossible to take action upon. For whilst gas's smell, for example, may only permit its detection, from the interpretation of snapshots of only this aspect, several extremely important governing actions may emerge – from the shutting off of gas flows at emergency valves, to the ventilation of properties, the evacuation of bodies, and the notification and deployment of engineers to repair the governing apparatus. Other traces may also be collected in the event of an escape. Handheld gas detectors may, for example, be deployed to locate the presence of gas and its atmospheric concentration, and from these assessments, new forms of action, including pipeline repairs, evacuation, or controlled ventilation may be made possible. Again, in a similar way, hazardous phenomena such as the loss of life may be cancelled out. Other sensors such as FLIR[123] cameras (used by fire service personnel to render methane clouds visible in real time)

[123] "Forward Looking Infrared Radiometer".

and atmospheric modelling software such as ChemMET and FireMET[124] may also be used to assess gas's contingent relational associations and to thereby take informed action upon it.

We can therefore observe within these latter examples, a number of attempts to produce a provisional reflective architecture. A series of mobile devices are deployed in the event of a gas escape, and actors swell around the gas to create an apparatus through which facets of gas's ontological structure are rendered knowable and actionable. The extent to which escaped gas can be accounted for within these apparatuses is much more limited than it was within the more rigid gas network, however. As the gas cannot be held still within the focal ranges of these devices, the traces that are produced are limited in terms of their variety, accuracy, reliability, frequency and speed. As a result, natural gas becomes far less coherent in the event of the escape, and the capacities of governing assemblages to control its movement and agency are severely reduced. This typically results in a shift in the modes of governance that are employed in relation to gas. Rather than controlling natural gas's circulation and manipulating practically every aspect of its known circulatory qualities to pursue various agendas such as safety, or the security of supply, governance practices are forced to shift to a mode of threat mitigation in which efforts are instead directed at simply preventing the emergence of worst-case scenarios, and limiting the extent of gas's negative affects.

We can therefore observe the formation of various kinds of complex security apparatus that have been carefully constructed around circulations of natural gas. These apparatuses have been specifically designed to reflect aspects of

[124] CheMET and FireMET are two different software systems supplied by the MET Office for use by the emergency services. CheMET is used for modelling the dispersion of chemical releases, and FireMET is used for immediately assessing weather conditions and their relationships with chemical releases, whilst full CheMET reports are being developed (Interview, Resilience Manager, Durham and Darlington Fire and Rescue Service, 2015).

gas's momentary ontological configurations back to centralized points of observation whilst the gas circulates, and in this way, they enable gas's effects to be rendered more-or-less coherent, and action to be taken upon it. By comparing the visualizations of gas that are produced through these apparatuses to already established knowledges, or 'blueprints' of gas's known possible relations, I have demonstrated how attempts can be made to facilitate, cancel out, or compensate for particular forms of gaseous phenomena.

I have also described in this section however, how the inflexibility of these apparatuses can result in gas that escapes their gaze rapidly losing coherence and human intelligibility, a situation that can lead to natural gas becoming more difficult to take action upon and to control. Whilst I have discussed the way that attempts may be made to assemble provisional architectures around escaping gas and to render aspects of it known, I have also demonstrated how these architectures, perhaps unsurprisingly, cannot produce the clarity of visualization that more rigid infrastructural apparatuses can. They are therefore necessarily limited in the forms of governing action that they make available.

V. Conclusion: Creating Coherence

In this chapter, I have described how a security apparatus has been constructed to render a moving gaseous target actionable through a series of specialized knowledge practices. This apparatus has been shown to have been designed specifically around the challenging materialities that are presented by natural gas; namely, the ways in which its invisibility, intangibility, and natural odorlessness have resulted in it typically only becoming humanly intelligible in a spatially and temporally incoherent manner. I then described how this apparatus seeks to render gas's humanly-intelligible affects more-or-less coherent over time and space in ways that enable a variety of securing actions to be taken upon it.

Gas has been shown to be rendered actionable principally through two sets of practices. Firstly, attempts have been made to construct 'blueprints' of gas's spaces of possibility. Drawing upon DeLanda (2013), I have described how humanly-intelligible traces of gaseous affects have been systematically produced through techniques such as experiments, investigations, simulations, and speculations, and I have shown how, through the analysis of these traces, the relationships between gas and other elements – and the way that these associations can contribute to the emergence of particular gaseous phenomena – have been identified. I have demonstrated how the lines of contingency that lead to particular phenomena have come to be systematically translated into more-or-less stable maps, or 'blueprints', of its field of possible relations, and I have described how these maps can be seen to take various forms, including government legislation, scientific papers, investigation reports, and industry standards. Through the creation of such blueprints, I have suggested that we can understand aspects of gas's ontological constitution to be rendered humanly intelligible and more-or-less spatio-temporally coherent in ways that allow for different forms of action to be taken upon gas's relations in the present in order to facilitate, cancel out, or compensate for, the emergence of particular future gaseous phenomena.

The second way that gas has been shown to have been rendered actionable via this apparatus is through the production of gaseous 'snapshots'. These snapshots are similar to blueprints in that they also involve attempts to map out gas's fields of possible associations and the forms of gaseous phenomena that could emerge. Yet unlike blueprints, snapshots involve attempts to visualize gas's different associations as they are in the process of their becoming. By then comparing these snapshots to blueprints, the forms of agency that are presently available, or are likely to soon become available to the gas, can be identified and acted upon. In this way, gaseous futures are rendered actionable in the present, with actions being taken upon the gas and its constitutive associations whilst it is in motion, and as it transforms across its circulatory journeys. These forms of contingent relational association, and the kinds of emergent phenomena that can develop during gas's circulation, form the focus of the following two chapters.

Finally, I argued that the visualizations produced of gas's emergent agency across its circulatory journeys, and the forms of actions that can accordingly be taken upon the gas, have been further expanded through the construction of a complex reflective apparatus that has been built around gas's circulatory routes. This apparatus, I have argued, is specifically designed to transmit gaseous snapshots back to particular centralized points of observation in a way that renders the gas and its immediate relations more-or-less spatio-temporally coherent, and which allows action to be taken upon gas at a distance.

In these different ways, I have attended to the specificities of natural gas's material qualities as they appear throughout its circulation, and I have explored how these qualities are productive of a highly particular set of knowledge practices and securing actions that have been assembled around the gas to render it actionable at different points in space and time. In the next chapter, we stay with these qualities. I describe how the manner in which gas circulates as it travels between nodal points also assumes particular qualities that have implications for the forms of risk and opportunity that can be seen to become associated with its transport, and that have necessitated particular kinds of security practice to be employed across its circulatory journeys.

5

Beyond (Pipe)*lines*: Complicating Circulations and their Governance

"One striking characteristic of such movements, and the paths they create, is that they are nearly always winding and hardly ever straight"

Ingold (2011; 129) "Footprints through the Weather-World"

"Look from above at a penny on a table, then lower your gaze. The circle becomes an oval, squishing gradually until, as your eye reaches the table level, only a straight line remains"

Sousanis (2015; 22) "Unflattening"

I. Introduction

Having examined the way that gas circulations are rendered actionable through the deployment of a complex reflective apparatus that surrounds its circulatory routes, I now turn to explore the ways that the circulatory qualities of gas – the ways in which it circulates – are productive of particular forms of risk and opportunity, and become the focus of security's practice.

Stretching out across the earth's surface, pipelines are typically imagined as thin, silver lines of bolted steel through which constant flows of energetic molecules are propelled. Traversing diverse terrains and multiple countries, they represent the quintessential model of contemporary global circulation. They are simple uniform conduits, direct trajectories between one or more points. Through them, liquid and gaseous products are transported effortlessly, smoothly, and efficiently: seemingly without impediment from any form of friction. They represent a perfect kind of circulation; a physical manifestation of a modernist ideal that values speed, fluidity, efficiency, and global connectedness. They are the model of circulation *par excellence*.

This circulatory ideal has often been reflected in contemporary academic accounts of circulatory security. Security researchers have become fixated upon circulations and the practices of security that are deployed upon them (Dillon 2005), yet circulation has typically been framed as uniform, featureless and linear. According to this ideal, movement has been assumed to be unproblematic, and little attention has been paid to its specifics. Instead, circulation is treated simply as something that occurs between point 'A' and point 'B'. It is bland. It is unidirectional and featureless. It is arrhythmical. It consists of single straight lines; flat trajectories that connect two distanced nodes. As such, the bumps, textures, velocities, volumes, forces, paths, bifurcations, reversals, transformations, rhythms, embodied experiences, and other manifold qualities of circulations have been erased. Circulations have been reduced to simple lines.

Conceptualizations of security in the academic literature have also been limited through these assumptions. Rather than imagining a series of practices that are employed along and throughout circulatory journeys, security scholars have often presented security as taking the form of a series of practices that firmly reside within these 'A' and 'B' nodal points. As I described in chapter 2, this has particularly been the case within the energy security literature, in which performances of security have been simplified to the extent that the qualities of energy's movements have been almost entirely erased. The movement of energy products between their points of production and consumption has again been rendered immaterial and featureless. It is presented as a simple matter of circulatory maintenance that results from transactions between energy producers and energy consumers, insecurity arising in the event of turbulence within these agreements.

In this chapter, I challenge these assumptions by attending to gas's circulatory journeys between such centralized nodes, describing various different qualities of gaseous circulations and the ways that they can be seen to present various opportunities and challenges for security's performance. In this endeavour, I seek to problematize the pipeline and to make strange these seemingly perfect circulations, showing how an attention to their specific characteristics *between nodes* is urgently needed in accounts of security's contemporary practice. This is achieved through a detailed empirical analysis of gas's circulation within UK transmission and distribution pipelines, in which I offer an account of the consequences that their myriad aberrant qualities may have for our understandings of security governance.

Notably here, I draw upon Timothy Cresswell's (2010) work regarding the politics of movement. Situated within the wider literature on mobilities, Cresswell has identified a series of features of circulatory movements that, in various different ways, bring about particular kinds of politics. Whilst valuable, I suggest that Cresswell's work can be expanded, particularly with regards to the politics that surround the mobilities of materials – a kind of circulation that is notably absent from his account. Building upon Cresswell's analysis, I therefore draw out six circulatory qualities, each of which, at different locations in space and time, can be seen to have implications for the forms of (in)security that surround natural gas. These include: the convoluted paths and circuits of circulations (section II); their volumes (III); their materialities (IV); the forces that they exert and the forces that are exerted upon them (V); their relative velocities (VI); and their rhythms (VII).

II. Paths and Circuits

Let us begin at an obvious starting point: problematizing the notion of the straight line within security scholars' depictions of circulations. On a map, pipelines may appear as simple, uniform, mono-colour lines (see figure 1, p.17). There is little to note of them; no textures, no volumes, no materialities, no dimensions (apart perhaps, from their length). Yet whilst this archetype suggests that piped gas may travel in linear, unidirectional movements, the circulatory paths that are undertaken by gas are actually far from simple.

Non-Linear Paths

We can begin to trace the intricacy of gas's paths by exploring the geographies of the UK's national transmission system and local distribution networks. In terms of its geography, the NTS is necessarily more linear than distribution networks. Its linearity serves two main governing functions. First, it facilitates a reduction in the amount of frictional force that is exerted upon gaseous molecules by the pipeline walls – the fewer the number of pipes and the larger they are, the smaller their surface area is compared to the amount of gas that is being transported. This is important, for an enormous amount of energy is required to provide gas with the necessary motive force for it to circulate on a national scale. The directness of gas's paths is thus beneficial for ensuring the security of supply, for it directly affects whether gas can be practically delivered to consumers. At the same time, the reduction in friction also beneficially affects gas's cost, due to the smaller amount of energy needed to facilitate its transport. This is also important because compression costs are folded into the energy bills of consumers and can affect the gas's affordability[125].

[125] Interview, Emergency Operations Manager, National Grid, 2014.

The second benefit of this linearity regards the ways in which National Grid can monitor and protect the system from particular kinds of threats. Such threats include damage caused by external actors (such as groundwork machinery), or from processes that are internal to the pipeline, such as corrosion (which can create inconsistencies in the thicknesses of pipe walls and reduce their ability to contain gas). The relative simplicity of the NTS permits the application of several governance techniques for addressing these threats that would otherwise not be possible. External threats, for example, can be monitored through aerial surveillance – the NTS's relatively linear paths allow for helicopters to easily and regularly follow the length and breadth of pipelines to check for encroaching developments[126]. Internal threats on the other hand, can be monitored and responded to in advance through the use of pipeline inspection gauges, or 'PIGs' – tools that can sense for inconsistencies and developing weaknesses within pipe walls. Linearity is again important here, for the shape of the network permits these devices to be transmitted across long lengths of pipe, and for them to then be easily extracted at the other end. If these pipelines were to bifurcate between the point at which they were inserted and extracted, they would likely get stuck or lost within the system.

At the same time as providing opportunities for certain forms of governing practice however, the linearity of the NTS also introduces a range of insecurities. Because large areas of the UK are dependent upon single NTS pipelines for their supply, the linearity of this network makes it vulnerable to the emergence of constraints upon individual pipelines; such constraints potentially resulting in the interruption of supply to millions of consumers[127]. One particular kind of constraint this linearity introduces is the possibility of sabotage, whereby consumers could have their gas supply interrupted by the intentional severance of critical pipelines. This recognised vulnerability has

[126] Interview, Emergency Operations Manager, National Grid (2015).
[127] IGEM Annual Conference presentation by Chris Train, CEO National Grid (2014).

therefore led to the development and implementation of a series of additional security practices around gaseous circulations, including the subterranean concealment of gas pipes and the restricted circulation of accurate maps of the precise outline of the NTS[128]. In this way, we must appreciate how, even when circulations *are* more-or-less direct, these particular qualities can have significant implications for the way that security is performed; new forms of governance, and new forms of insecurity being made simultaneously possible.

Whilst I have begun by drawing attention to the linear qualities of the NTS here, the paths that gas actually takes within this system are far more convoluted than they might first appear. To help us to understand the intricacy of these paths, we need to begin by examining the functions of the pipe. As Cresswell, citing Deleuze and Guattari (1987), importantly highlights, circulations rarely move freely and evenly over smooth space, but are instead ordered and channelled into acceptable conduits as they move across diverse terrains. Such ordering can take many forms, from natural channelling processes such as valleys and drainage basins that order flows of water, through to anthropocentrically-governed circulations, such as aeroplane movements (whereby circulatory routes are established through pre-conceived flight paths, geopolitical situations, weather, pilots and air traffic controllers), roads (where the movements of road users are defined by the location of road infrastructure, road safety laws, signage and police), and conserved walking paths (whereby walker behaviour is guided away from vulnerable ecological sites by the location of footpaths, the exclusion of information on those sites from maps, and the use of signs). The spatial ordering in many of these circulations can be seen to operate under manifold concerns for security, but all broadly cover either the way that these circulations affect space (as, for

[128] Attempts are also made to conceal critical infrastructural assets (such as compressor stations) behind high soil banks and through the erection of anti-climb fencing. Notes from Site Visit to National Grid House (2014).

example, in the case of footpaths in conservation areas), or the way that space affects these circulations (as in the case of flight paths and the avoidance of certain hostile airspaces). Furthermore, the governance of these circulations can be seen to operate through a variety of techniques, from the construction of constraints to movement (as in the case of the routes of rivers, roads and footpaths), to techniques of active steering (planes and cars) and directional persuasion (planes, roads, footpaths). In each of these cases, one or more of these techniques is employed, and each is backed up by a distributed network of actants that work together to reinforce the path along which an entity circulates.

This routing and ordering of circulations is the principle function of pipes. Pipes physically constrain the gas and limit the directions in which it is able to move. Yet despite these physical constraints, gas cannot be directly steered or controlled; it has to be solicited into taking particular routes. Its movement is thus induced by raising the pressure in one section of pipeline to a point at which it exceeds the pressure in another[129]. As a result, should the pressure in one area of a pipeline rise or fall, then the direction of gas flow may change. Gas will not move in a uni-directional manner, but may move back and forth.

Friction also repeatedly overcomes the motive force that is applied to the gas (thereby reducing its pressure). Because of this, it has to be coerced into moving through the use of periodic re-compression at compressor stations located around the network. Furthermore, if the pressures at both ends of a pipe end up being the same, then the gas inside will come to a stop. For each of these reasons, gas does not take linear paths along pipes. It goes back and forth, changing direction and speed, and sometimes comes to a halt.

[129] Low pressure is usually achieved by taking gas out of the system through its consumption.

This movement is further complicated by the fact that gas can enter the NTS at any one of seven reception terminals, or from the any of the multiple storage facilities that are located across the country[130]. National Grid (the NTS operator) has no direct control over when and where the gas will be delivered into the system, and it also cannot directly control where gas is taken out. As such, it is limited in its ability to govern the two main drivers of gas's movement; its entry and exit. Instead, it has to monitor and manage the arrangement of pressures across the grid through the use of compressors; a governance practice known as 'balancing'. This practice is essential for ensuring the continued supply of gas to consumers. As such, gas does not move linearly from one end of the country to another - it is introduced to the system at multiple points, and is shunted around through these pipelines, according to where it is needed.

Whilst the NTS does consist of a more linear arrangement of pipes than distribution networks, it also does not consist of singular straight lines that simply transport gas up and down the country. At different points, pipes join and cross, and single gas streams are forced to split and diverge along multiple paths. Indeed, whilst certain sections of the NTS are served by single pipes, the design of this system is such that areas serving large numbers of consumers will be served by multiple pipes. In this way, a form of operational resilience is built into the system[131]. Should a fault or constraint develop upon a pipeline (for instance, if maintenance work has to be conducted in a certain area), then the gas may be persuaded to take alternative routes, circumventing the paths where the constraints are located. In this way, the creation of multiple circulatory paths is a strategic governance practice that ensures the security of supply, even when stress is placed upon the network.

[130] Interview, Emergency Operations Manager, National Grid (2014).
[131] Interview, Emergency Operations Manager, National Grid (2014).

Finally, NTS pipelines are often not precisely straight. Indeed, they are semi-flexible and often bend around landscape features. For instance, most of the NTS has been designed to avoid settlements and other infrastructural developments so that the risk of people being injured in a gas escape can be reduced. Avoiding developed areas also further reduces the likelihood of an incident taking place, for the pipes are not located in areas where the ground is as frequently disturbed. As the emergency operations manager at National Grid explained:

"We have had a couple of major incidents, but they are pretty rare considering the amount of pipeline we have got in the ground. And that just comes down to the fact that the pipeline is in areas where people don't interfere, you know, we don't go anywhere near towns, the off takes are well out of the way" (Interview, Emergency Operations Manager, National Grid, 2015)

Gas's circulation becomes even less linear when it enters the distribution networks. Distribution pipes, unlike NTS pipes, are extremely rhizomatic. They branch off from the transmission system like capillaries, radiating out into thousands of divergent routes that spread across vast surface areas, and transporting gas to millions of dispersed properties. This rhizomatic arrangement results in a network that is far less vulnerable to a single failure, (for less consumers are reliant on any one individual path[132]), but it also simultaneously opens up new forms of vulnerability.

Whilst it is theoretically possible to use inline inspection devices (PIGs) on small diameter pipes, the branching nature of distribution networks means that these devices would often get stuck at pipe junctions. The developments built on top of these pipes would also likely make their extraction difficult[133]. Pipeline inspection is therefore simply not possible within distribution systems, and this makes it far harder for network operators to accurately assess the extent of

[132] Interview, Health, Safety and Environment Manager, National Grid (2014).
[133] Site visit, PII Pipeline Solutions (2014).

corrosion on their pipes, and to locate and repair these pipes before they begin to leak.

The rhizomatic geography of distribution networks also introduces further vulnerabilities. Their wide spatial spread makes it far harder to protect these systems from external interference, and because they necessarily have to permeate urban fabrics that are constantly being dug up and redeveloped, they are far more vulnerable to accidental damage. Added to this, the increased proximity of property and infrastructural developments on the surface makes these pipes inaccessible, and getting to them for repair is consequently often expensive and disruptive. When combined with the increased population density that surrounds these pipelines, the geographies of distribution networks can therefore be seen to generate a plethora of potentially life-threatening vulnerabilities.

Distribution networks are also demonstrative of how circulatory pathways can exhibit a range of dimensions and textures. Whilst figure 1 (p.17) represents pipelines as identical and uniform, each pipe within the UK's natural gas infrastructure possesses distinctly different qualities. This is clearly visualised in 'Image 11' in Appendix C, where we can observe a complication to the pipeline map. Instead of single, straight, and even lines that have monotone colours, this map depicts multiple lines that have numerous colours, textures and labels. The different textures and colours indicate the different pressures at which gas is transported through these pipelines (solid red=low pressure, dotted blue=medium pressure, dotted green=high pressure, dashed yellow=regional high pressure, solid and dotted purple=abandoned pipework) and the labels by their sides indicate the different diameters, thicknesses and materials of these various pipes (90PE for example, indicates a 90mm pipe made of polyethylene). These gaseous pathways can consequently be seen to undulate; their diameters expand and contract at different points, assume different wall thicknesses, and change in the materials that they are constructed from.

Such qualities are important, for they have direct implications for the capacities of these pipes to govern gas's circulation. Larger diameter pipes, for example, can transport greater volumes of gas, and are typically stronger[134]. Thicker pipes of different kinds of materials may be more expensive, but could offer greater resistance from penetrative forces such as diggers and drilling machines (or from the vibrations of heavy traffic). The spatial context of pipes is also important, for their assignment to different areas involves a particular kind of security practice. If, for example, a pipeline has to pass nearby a sensitive area such as a railway, road or settlement, then wider diameter, thicker pipelines will be installed using stronger materials. In this way, the risk of the gas escaping and these other infrastructures being disrupted, is reduced[135].

In these ways, the qualities of the paths that gas takes have manifold implications for its governance. Each aspect of its journey, whether linear or convoluted, its relationship to geographical features, its directions, or the way in which it undulates as it circulates, presents a series of different challenges and opportunities for security performances. As a result, we cannot understand gas's circulatory governance without also attending to the specific qualities of its circulatory paths.

Circuits

In addition to the complicatedness of these paths, security scholars have also commonly overlooked the '*circular*' qualities of circulations. Very little emphasis

[134] Interview, former Network Director, Northern Gas Networks (2015).
[135] Industry standards – IGEM (1995).

has been placed upon the round trips that entities make in this literature – the way that their circulations fold back into one another and are transformed and reiterated. Instead, the movements of bodies, materials and things have tended to be simply traced between one point of departure and another point of arrival[136]. We therefore need to ask how the circuit might change our perception of circulations, and how it might begin to be seen to have implications for the performances of security conducted around them. In the following paragraphs I thus trace out some tentative observations regarding the consequences of thinking about gaseous circuits.

Observation 1: The circuit challenges the way that we treat circulatory points of origin. Rather than seeing a circulation, such as that of natural gas, as beginning at a particular location (typically for gas, its point of extraction), it may be useful to trace the journeys of these entities back from their assumed starting points. In studying entities' earlier journeys, a number of relevant political issues may come into focus. For natural gas, the organic materials from which it was produced, the compression and heat of the rock around it, and the time with which these processes took to produce it, all have implications for the governance of present-day circulations of gas. For instance, the depths at which it forms, and the rock types that formed it, constitute impediments to the speed of its extraction, but at the same time provide valuable indicators for deducing its subterranean location. Similarly, the time that gas takes to form through these geological processes has important consequences for traditional conceptions of energy security. Continued societal reliance upon fossil fuels, the speed at which they are being depleted, and the length of time that they take to form, are for example, the major contributing factors behind recent fears over peak oil (Bridge, 2010). As such, natural gas's geology is productive

[136] There has been recent work elsewhere that has begun to examine the political implications of these round trips (for example, see the work on circular economies developed by Gregson and Crang, 2015, and Gregson et al. 2015). As of yet however, the implications of circularity for security have received little academic attention.

of particular kinds of security politics, and the circuit can therefore help us to go beyond the origins of entities that first present themselves, forcing us to consider the political entanglements that these circulating elements may bring with them as they move in the present.

Observation 2: The circuit challenges the way that we treat circulatory end points. Gas requires us to acknowledge that consumption is not the end point for its political life. Instead, consumption is a point of transformation. Gas continues to circulate beyond consumption, both in terms of the energy that is contained within it, and in terms of the transformation of chemical matter. Energy cannot be destroyed; as gas is consumed, its energy is converted to heat, light, noise, kinetic motion, or is stored in other materials. Energy in these new forms may also have new political effects (the stored energy in gas, for example, may convert to heat and light and burn human bodies). Whilst the circulation of this energy and its affects may be impossible to trace beyond a certain point due to its minute dissipation, we can still observe a range of diverse governing practices that have emerged around some of these transformations[137].

Similarly, gas's chemical matter does not simply disappear – even when it is burnt. Whilst gas is relatively clean compared to other fossil fuels, it still produces a range of materials during its combustion. Gas can produce a sooty mixture of solid materials, and can also release a range of other gases. Whilst it may no longer be recognised as natural gas in these instances, the atoms that existed previously continue to exist after burning, albeit in new combinations. These new materials may similarly open up new forms of politics. Two particular relevant examples in this instance concern the production of carbon

[137] Such practices can be extremely broad, from the installation of fire extinguishers that are designed to quench the heat of gas fires, to the introduction of gas ovens with explosion relief panels that are designed to absorb gas's developing kinetic energy.

monoxide and carbon dioxide. Carbon monoxide is an odourless, invisible, and extremely toxic gas that is preferentially absorbed by the body over oxygen - a form of agency that can lead to bodies becoming starved of oxygen and their eventual death. Its production has therefore necessitated the formation of a number of governance practices that try to avoid human casualties, such as public awareness campaigns that draw attention to the causes and symptoms of carbon monoxide poisoning[138]. Carbon dioxide, in contrast, has pronounced insulating properties that can affect global climate. Attempts have consequently been made to govern its atmospheric release through a wide range of initiatives, including the creation of regulations on permitted vehicular emissions, reductions in the amount of coal that can be burnt for electricity generation, and the promotion of renewable energy technologies. In these ways, natural gas can therefore be seen to continue to have a political life beyond its cremation and to circulate beyond its points of consumption.

Observation 3: The circuit forces us to recognise a multiplicity of points of transformation. Natural gas's points of domestic consumption are only one of many potential points of transformation. It is consumed within power stations and large factories; it is ejected from overpressure valves on pipeline assets; it leaks from battered and ageing distribution networks; it escapes during the opening up of pipes for maintenance; it is vented to atmosphere in processing terminals; it is consumed for powering compressor turbines and other pipeline assets; it is injected into salt caverns for storage. Domestic consumption is thus only one point of its departure: gas takes multiple divergent paths throughout its circulatory journeys[139]. Again, each of these paths also involves the emergence of new political situations. In its leakage and atmospheric circulation for instance, methane comes to have particularly pronounced political effects. Methane has a global warming potential (a relative measure of

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[138] Site visit - 'Carbon monoxide kills' stand at IGEM (2015) emergency planning conference.

[139] Site visit – National Grid House, 2014.

the amount of heat that a gaseous material traps within the atmosphere) that is 84 times higher than carbon dioxide over a 20-year timescale, and 25 times higher over a 100-year period (IPCC, 2014). It is consequently one of three major greenhouse gases that have been identified by the International Panel on Climate Change (IPCC) as playing a critical role in the change of global climate. As a consequence, gas's leakage from pipelines has come under increasing scrutiny by the UK government, and is now subject to multiple initiatives to reduce the quantities in which it is released (DECC, 2012). As such, our perspective of the pathways that circulations may take needs to be widened, and we must remain open to the fact that gas may take alternative paths that may generate new forms of (in)security.

III. Voluminous Circulations

The second quality that I wish to draw out in this chapter concerns the voluminous properties of circulations, and the way in which these properties may have implications for the ways that security is performed around circulating elements. Such qualities are notably underplayed in Cresswell's (2010) account. In this section, they are explored in two ways. First, I look at the three-dimensional spaces through which circulations travel, and second, I look at the property of being voluminous – of circulations having volume.

Movements <u>through</u> Volumes

Attending to the volumes through which circulations move involves taking into account the vertical dimension of circulatory journeys and the way that, at any one moment in an entity's circulation, its vertical context may have particular significance for the way that security is performed in relation to it. Verticality has already drawn some attention from a number of scholars, particularly in response to complaints about the underlying conceptual horizontalism within human geography. Many of these writers have looked towards vertical spaces above the earth's surface for understanding geographical phenomena, and a particular focus has been placed upon the air within this literature, with explorations of the role of the air in warfare and military operations (Graham, 2010a; Gregory, 2011, 2014; Coward, 2013); aerial mobilities (Cwerner, 2006; Graham, 2014), and aerial life (Adey, 2010). A smaller literature has also examined the vertical in relation to the urban environment (Graham and Hewitt, 2013; Harris, 2015; Elden, 2013). Yet, whilst security and circulation have entered these accounts, these references have been tangential to broader discussions of security and circulation within security studies. This is a situation that is mirrored in the smaller, but rapidly growing, literature concerned with below-surface verticalities. Such studies can be largely divided into those that have been concerned with oceanic depth (Steinberg and Peters, 2015; Dodds, Copley and Sandwell, 2014; Bull, 2011) and those that are concerned with the subterranean (Bridge, 2014b; Clark, 2013a).

Natural gas undergoes complex vertical journeys that extend both above and below the earth's surface. Formed deep beneath the earth, it often travels for great distances underground and is frequently transported beneath the sea in vast pipeline networks. It also undertakes substantial journeys above the surface, rising into above ground installations for easy operational access, being stored within towering gas holders in liquid or gaseous form, traveling up buildings through pipes and into the highest points of skyscrapers, or circulating freely within the atmosphere. At other times it is also injected back into the earth, for storage within salt caverns, aquifers and depleted gas fields (Fevre, 2013). Throughout its circulation natural gas therefore makes extraordinary vertical ascents and spectacular subterranean descents.

Each of these vertical contexts must be evaluated for the ways in which they have implications for performances of security. The underground, for example, can be seen to produce both insecurities and opportunities for governance. Over 180,000 miles of pipe are buried beneath the surface of the UK (ENA, 2013), and as such, the character of UK gas transport networks is distinctly subterranean. Yet as described previously, burying pipes is not merely an act of convenience – it is one of the most consistently employed tools in gas's governance. As Peter Ackroyd (2012, cited in Elden, 2013) observes, the ground is often enrolled to protect critical infrastructure from external manipulation, due to the way that it offers two types of distancing. First, it creates a perceptual distance between humans and the buried infrastructure (the ground's opacity obscuring these infrastructures and making their whereabouts uncertain), and second, the ground provides a physical separation between the gas and different kinds of external threat. The ground therefore assists in protecting pipes from threats such as accidental damage and intentional sabotage.

In these two ways, we can understand the vertical to become enrolled within practices of governing circulations – depth here providing a degree of safety for circulations by making them undetectable and inaccessible. Yet the underground must also be appreciated for the ways in which it introduces a series of challenges for governance. In particular, the distancing of services from external interaction often makes them difficult to survey and challenging to maintain. As described in the previous section, specialised inspection techniques have been developed to survey larger transmission pipes internally, but assessing the health of smaller distribution assets presents major challenges for network operators (Jardine et al., 2012). The opacity of the ground also creates risks, making the gas infrastructure more vulnerable to accidental damage from machinery used for groundwork and farming, with the majority of major leaks resulting from third party damage[140].

Different governance practices have consequently emerged as a means of trying to deal with these challenges. Newly installed gas pipes for example, have to have a yellow-coloured outer layer to make them more visible and easily identifiable by ground workers, and in a similar manner, pipeline markers are installed in locations where the NTS passes under roads, in order to alert road maintenance workers of their presence. Furthermore, specialised industry advisory services, such as 'Dial Before You Dig' and 'Linewatch' provide a point of contact for developers to check for the presence of gas pipes before they begin excavation.

It is not just gas's underground verticality that has implications for governance however. Gas's above ground travels also reveal a variety of contexts in which distinct differences in altitude have implications for the insecurities that gas presents. Above ground installations, for example, are often more visible and perceived to be more vulnerable than buried assets. Because of this, they are often subjected to additional methods of concealment and protection, such as the erection of fences and earth barriers, and the employment of security guards. At higher altitudes however, gas travelling through high-rise flats and multi-occupancy dwellings is considered to present greater safety risks due to the number of people that are exposed to the impacts of a single incident. A major gas explosion in 1968 at Ronan Point[141], for example, prompted a wide-scale revision of the UK's building regulations and the creation of a new set of industry standards specifically relating to gas installations within tall, multi-occupancy dwellings (IGEM, 2012). At a higher altitude again, atmospheric

[140] Interview, former Network Director, Northern Gas Networks (2015).
[141] Ronan Point was a large block of flats located in London.

methane presents a set of completely different insecurities regarding global climate.

Figure 11 - Photograph of Ronan Point, 1968

These examples demonstrate the significance of altitudinal variations for the forms of (in)security that surround one particular kind of circulation. Whilst these examples showcase the significance of the vertical dimension in conceptualising the way that security relates to circulation however, we also need to be careful to not simply replace horizontalism with a new orthodoxy of verticalism. Indeed, this is a claim made by Elden (2013), who insists that we engage with space not just vertically or horizontally, but by appreciating its full three-dimensionality. Circulations, as Elden notes, move through *voluminous space*, traveling at different angles and different (in/de)clines. As such, the implications of these three dimensional movements must also be assessed.

Figure 12 - Photograph of a water trap used for separating water from town gas (Fakenham Gas Museum, 2014)

In the case of natural gas, gradients have significant implications for the forms of (in)security that emerge in relation to it. Most notably, gradients cause problems in conjunction with the ingress of water in distribution systems. Water typically enters these networks when a nearby water main bursts. The high pressure with which water is transported often leads to it violently churning up the soil around gas pipes, quickly boring holes through them and allowing the water to enter. Once inside the gas pipes, it can then run down declines and settle at low points in pipe networks. This is problematic, for it can generate uncontrolled interruptions in gas supply[142]. Such interruptions are potentially dangerous because they can temporarily cut off gas supply to properties, the flames of appliances being extinguished only for the gas to return at a later point. With the flames no longer consuming it, the gas can then freely enter these properties and accumulate in potentially explosive volumes.

[142] Such interruptions are 'uncontrolled' because the gas supply is not reliably shut off; water may move within the system and cause intermittent interruptions to supply.

Whilst water ingress is less common in contemporary gas networks than it was in the past, it still presents a significant source of threat to consumer safety. Indeed, previously, gas was typically so 'wet' (due to the way it was manufactured) that water traps, such as the one in figure 12, were commonly installed across distribution networks at system low points where water was likely to accumulate. These traps enabled water to fall out of the gas stream without interrupting gas flow, and the water could then be siphoned out of the bottom, by an engineer at street level. Today, contemporary natural gas is dehumidified before it enters the NTS[143], but these gradients can still lead to uncontrolled supply disruptions if water manages to get into the system[144].

Voluminous Circulations

In addition to the voluminous space through which circulations travel, we must also appreciate how circulations have voluminous qualities. There are two ways that I suggest we might consider circulations to be voluminous in the case of gas. First, I suggest that we can think about volume in terms of *quantity*. This is perhaps most easily seen in the circulation of people, but it is also relevant to most forms of circulation – from flows of gas molecules, to movements of finance and bacteria. Importantly, the quantities of entities in circulation can give rise to different political situations; from contemporary fears over high immigration figures, to concerns over the tension between the large numbers of people passing through airports and the amount of friction that is created by contemporary security practices (Adey, 2004), or worries about the amount of money that is circulating in economies (Langley, 2014).

In the case of gas, quantity most commonly associated with the security of demand and supply. Too few gas molecules relative to the amount needed by

[143] Site visit, St. Fergus gas processing terminal (2014).
[144] Interview, Health, Safety and Environment Manager, Northern Gas Networks (2014).

a given consumer (nation, organisation, individual, etc.) for example, can result in insecurities for users. Alternatively, a surplus relative to demand can result in insecurities for producers, who rely on the revenues generated by the gas's sale (Lajous, 2004). Quantity is therefore at the centre of traditional conceptualisations of energy security.

The second way that I suggest that we might think about volume concerns the three-dimensional space that circulating entities take up. This is different from the previous distinction, in that certain circulations may not necessarily need to be physically voluminous in order to move in large quantities (as, for example, in the case of transfers of electronic finance). Dependent upon the size of the entity in circulation, the space taken up by these circulations may also be dramatically different, regardless of their quantity. Such volumes are again important, for they may have significant implications for the nature of their transport and the way that security can be performed around them.

Importantly for gas circulations, such voluminous qualities are dynamic, changing whilst it is in transit. Natural gas is extremely compressible, and its three-dimensional volume can consequently change dramatically, dependent upon the pressure and temperature of its molecules. Increasing its pressure can enable more molecules to inhabit the same space, and reducing its temperature to a point below -162°C will make it shrink and change state, from gas to liquid. In the process, it will reduce in volume by over 60000% (Mokhatab, Mak, Valappil and Wood, 2013), making its international shipment and sale economically viable. This, in turn, may have important implications for the way that national energy networks can manage the insecurities that are produced through their dependence upon a limited number of energy providers. As such, volume consequently becomes folded into practices of gaseous governance, with extensive effort being expended upon carefully regulating its volume by manipulating pressure and temperature throughout its circulation.

In these three ways, therefore – its movements through three-dimensional space, its quantities, and its three-dimensional volume – natural gas presents a range of opportunities and threats that, at different points in space and time, become entangled in performances of gaseous security.

IV. Materiality

A significant omission from Cresswell's (2010) analysis of the politics of motion regards the material qualities of the entities in circulation. Each body, object and 'thing' has its own particular material qualities that affect the way in which its movement can be governed. This is a major theme in this thesis, but here I wish to draw attention to three particular material qualities of circulations that have implications for performances of security around natural gas during its movement: its appearances, textures, and mutability. Amongst other material qualities, I suggest that these qualities are productive of a number of different forms of (in)security and come to affect the ways in which gas can be governed.

Appearances

Through its very invisibility, natural gas draws our attention to the significance that the visual appearances of circulating elements have for performances of security. As I have demonstrated in chapter 5, this invisibility plays a major role in the forms of governance that can be performed around it, and has resulted in a highly specialised reflective apparatus being constructed around natural gas in order to render its circulations perceptible so that it can be governed. As such, its appearance can be seen to be productive of particular performances of security that have been designed around the its specific visual qualities.

Gas is not unique in its invisibility however. Other entities may undertake very different appearances and become more or less visible at various points in time. One example can be seen in Marieke De Goede's (2007, 2012) work on terrorist finance, where she analyses the way that US financial institutions have come to regard the hard-to-survey qualities of physical cash as constitutive of particular forms of danger. Unlike electronic circulations of finance (which can be relatively easily traced), circulations of cash are harder to follow – a quality that De Goede argues has led to financial institutions to consider their circulations suspect, and a source of potential insecurity.

Visibility is not the only characteristic of different entities' material appearance however, and indeed, all circulations look different, depending upon the scales at which they are viewed. What might appear as a pipeline from a distance might also be seen as millions of individual molecules when viewed up close. Dependent upon the level of magnification, very different forms of (in)security may be observed in relation to these circulations.

For example, looking at gas circulations with a low magnification, they may be seen to become significant for security in terms of the number of million cubic meters of gas that enters and exits transmission and distribution networks at any one particular moment in time. Security from this perspective may be seen as a matter of a more traditional understanding of energy security, whereby the volume of gas entering the system must equal or exceed the volume of gas that is required by society.

If we examine gas at the molecular level however, we may perceive completely different forms of gaseous politics. As is explored in detail in chapter 7, gas's molecular composition at times becomes subject to a range of security practices that attempt to 'cancel out' particular kinds of gaseous qualities (such as its toxicity and corrosiveness), based upon their association with the emergence of particular kinds of gaseous phenomena.[145]

Perhaps unsurprisingly, geographers have been quick to explore the diversity of scales in which materiality can have social significance. Analyses have ranged from the work of Jane Jacobs on the material effects, and affects, of 'big things', such as globally significant architectural projects, and other studies have focused on the other end of the spectrum, looking at the political significance of the molecular (Braun, 2007; McCormack, 2007; Dixon, Hawkins and Straughan, 2012). A number of authors have also begun to trace the significance of looking at materials at the nano-scale (Anderson, Kearnes and Doubleday, 2007; Anderson, 2007; Kearnes, 2010). Little work has yet been conducted on this topic in relation to security however, despite the fact that each of these different scales may produce very different perceptions of the material qualities of circulating elements and the security performances that surround them.

Textures

Natural gas also draws our attention to the different kinds of textures that circulations may possess. The quality of being gaseous results in gas assuming no fixed form; it fills volumes and takes the shape of the walls and barriers that contain it. It also causes it to move as a fluid through pipes, and because it is less dense than air, it is buoyant and rises vertically unless impeded. It is also compressible, making large quantities of gas more easily storable, and providing it with the necessary motive force to transport it along pipes. In different contexts (many of which are explored elsewhere in this thesis), each of these material qualities will come to have different and significant implications

[145] Site visit, St. Fergus Gas Processing Terminal (2015).

for the performances of security that surround it. Perhaps most clearly however, these qualities mean that, unlike solid and relatively stable energy products like coal, gas requires constant containment in order to transport it. Indeed, this has given rise to a series of other forms of insecurity. Until relatively recently for example, LNG transport was economically unviable on a large scale, and as a consequence, natural gas has had to be transported via expensive, inflexible and vulnerable pipelines. These requirements limited its adoption (Patterson, 2008). Moreover, as can be seen in the case of Russia's manipulation of gas supplies to Ukraine, the rigidity of these pipelines can introduce vulnerabilities for gas dependent nations that rely upon gas supplies delivered through single, fixed networks.

At times, gas can assume quite different textures, however. Grit and oils, for example, give gas two very different consistencies. These materials, which typically originate from wells during extraction, from locations where the network has been opened up for maintenance, or where mechanical assets such as compressors have leaked, can become suspended in the gas flow. Oils can also evaporate and become dust, integrating with the grit. As the senior engineer from National Grid described;

"[The NTS] is continually being opened up and shut again, and being re-welded, being cleaned out. You are just getting particulates coming in from all sorts of entry and exit points really…not necessarily entry points - gas turbines that we have on the system have oil seals…so they do, do, get weep a little bit - that oil does get into the system - what it does is it evaporates, because there is no oxygen in there. And it forms a sort of sludge, a gunge, and as it dries itself over time it becomes a load of very fine particles. Some of it stays liquid, but some of it actually oxidises off, um, not oxidises, it just becomes evaporated into the system…sometimes you get liquids that do exactly the same thing as they are taken through. But it's just general engineering dirt that is gradually taken through." (Interview, Senior Engineer, National Grid, 2015)

These abrasive and viscous qualities are significant for the way that the gas can be governed, for grit can erode and block systems, and oil can cover flow meters and affect their accuracy. These textures therefore can have important implications for security. If left unaddressed, they could cause substantial meter mismeasurements, damage pipelines and potentially block domestic appliances, leading to gas explosions. They can also provide the gas with carcinogenic properties, presenting risks to engineers working on the network. As the senior engineer continued:

"if you do see inside a pipe you can rub your hands around…and you get this very light brown dust…its um…I wouldn't do it with your bare hands because it might be carcinogenic. […] As you get further and further into a network, the size of the burners are getting smaller and smaller and smaller, and the pilot lights are getting very, very fine. And the manifold which you sometimes see in burners and boilers and in gas fires, maybe not gas hobs, but certainly boilers, are very, very fine and particles can start to build up and clog. Um…domestically that's not a great news story - you don't want to blow someone up." (Interview, Senior Engineer, National Grid, 2015)

In this way, the different textures that are assumed by natural gas across its circulatory journeys can be seen to also have implications for the forms of insecurity that develop in relation to natural gas's circulation, and for the way that security is consequently performed in relation to it.

Mutability

Finally, natural gas demonstrates how the material qualities of entities may change as they move through space. As is explored in greater detail in chapter 7, natural gas undergoes a wide variety of transformations throughout its circulation. Indeed, it is an inherently dynamic material. Throughout its circulation it changes in pressure and volume, it changes temperature and state, it will become more and less wet, and it will shift in its chemical composition, sometimes including toxic materials such as hydrogen sulphide, carbon monoxide, and carcinogenic dust. As such, it is constantly in flux.

In contrast to gas, other entities may hold their shape and qualities relatively rigidly as they travel over space and time. Latour's (1986) notion of the immutable mobile is one articulation of this, and numerous studies have described the political ramifications that the immutability of such materials can have (c.f. Law, 1986; Latour, 1986; de Laet, 2000). Yet security studies scholars have frequently made assumptions about the ontological stability of the circulating entities in their enquiries, and as such, the manifold ways in which these ontological transformations may have implications for the governance of different elements has often been overlooked. Mutability is not unique to gas. Bodies may change and look different from their passport photographs; food may decay and become toxic; pathogens may mutate, and would-be terrorists may experience changes of heart.

A simple example of the political relevance that gas's mutability can be seen in the way that gas changes temperature throughout its transit. Whilst gas's temperature constantly changes, due to the different temperatures of the soil, air and water surrounding gas pipes, the heat of the sun, the thickness and diameters of pipes, and the materials from which they are made, there are a series of locations at which gas undergoes a significant drop in pressure (typically at distribution off takes). This pressure drop can cause the gas to simultaneously dramatically cool down – a temperature change that is so significant that it can cause the water in the air and surrounding soil to freeze around pipes and connected assets. This can generate a range of insecurities, emergency valves and other operational assets sometimes ceasing up and stopping functioning. For this reason, at most locations where sizable pressure drops occur, boilers are employed to heat up the gas before it undergoes changes in pressure, in an attempt to prevent it from falling to a point where it will freeze nearby water[146].

[146] Interview, Emergency Operations Manager, National Grid (2015).

In these different ways, the dynamic qualities of circulating natural gas – here, its appearance, texture and mutability – can be seen to have a number of significant implications for the manner in which security is performed around circulating natural gas. As is a central theme of this thesis, I suggest that we cannot hope to come to understand the way that security is performed around other circulating elements unless we also attend to their dynamic material qualities.

V. Forces

When considering the way that circulations become entangled with concerns for security, we must further tend to the forces that act upon these circulations, and the forces that these circulations also exert. The forces that surround circulations have received little attention from security scholars to date, but valuable work has been conducted within the mobilities literature around the constitution and consequences of certain forces – motive force, and friction (Cresswell, 2010; Gill, Caletrío and Mason, 2011; Pesses, 2010; Anim-Addo, 2014). Very little attention has been paid to the way that circulations themselves, are forceful, however.

Motive Force

Motive force, as described by Cresswell (2010), is a fundamental prerequisite for circulation – objects have "to have a force applied to [them] before [they] can move" (p. 22). As I have described in relation to gas's compression, significant amounts of force are required to move methane molecules through pipes. Across the transmission and distribution systems, gas has to have force applied to it at multiple points, either by compression through the use of turbines and boosters, or through thermal expansion, whereby heat is applied to increase the space between molecules, and thereby increase its pressure (this is typically only practiced during processing, and is used in conjunction with other forms of compression)[147]. Importantly for Cresswell however, there is always a politics to motive forces. For gas compression, these political implications are manifold. Most obviously, following traditional understandings of the politics of the security of supply, compression is a closely regulated practice of gas governance, through which the delivery of gas to properties is carefully maintained; sufficient motive force must be applied in order to deliver gas to individual consumers. In addition to this rather basic understanding however, the following interview extract highlights a number of further political situations that surround the application of motive force to natural gas.

"So we use gas pipe turbines for a lot of [compressors], but we are phasing that out because its…they are not operating in the sweet spot, so it's a bit dirty to operate like that. So under the current emission requirements and things we're moving a lot of our fleet to electricity because they are, they are more efficient. You burn the gas elsewhere to make the electricity, but you burn that really efficiently. And then the electricity runs the system. But we have tended to use gas fired turbines to run our compressors in the past, but because we are trying to run at a range of different power outputs it means you are not operating in that sweet spot for most of the time. […] [W]e tend to have a range of units at each site, depending on where it is, the history really, when it was built. Because, you know, back, way back, we used to build, we would probably build more resilience into the grid than we do now. We are probably a bit more efficient about where we build er, multiple streams and things, but generally we build resilience into it. So you will tend to have a, your, main operating plan, which might be we will run unit A and that will manage this range of flows and pressures. And then if that fails, we will have, unit B will kick in and cover it. But what you might have is unit C and unit D as well. So, if you might say, well I'm going to run A and C in parallel. And if that fails you can move to B and D in parallel, or I might run A, B and C together. And what you can do, is what that gives you is a whole different range of what you can do. Because those engines will only create so much lift, what we call 'head', so in terms of pressure in and pressure out, the difference. The amount of flow that is going through at that time, there is a limit to that. There is an operating envelope. As soon as you start to get towards the limit of the flows or the pressure, then you maybe need to bring another unit online, or switch to a larger unit, but you've got a range of strategies at each compressor station there. But they are fickle things, so very difficult to operate. You know, we have a lot of problems with them. Failing and breaking down, and things like this. Which is why the resilience needs to be there, and why we are moving to the electricity, with gas-fired

[147] Interview, Emergency Operations Manager, National Grid (2014) and Interview, Operations Supervisor, Shell, St. Fergus Gas Processing Terminal (2015).

generation as back up now. So we will generally run electricity, but obviously, in a power cut …then we move to a gas-fired fuel line. So the resilience will be there." (Interview, Emergency Operations Manager, National Grid, 2014)

In this extended extract, we can thus observe a range of insecurities that are associated with the production of gas's motive force. First, there are practical operating requirements that necessitate the running of multiple turbines simultaneously to ensure that sufficient pressure to meet demand is created. Second, there are environmental concerns for energy efficiency, with references to National Grid's increasing investment in less carbon intensive forms of compression. Third, there are concerns for operational resilience, and the difficulty of dealing with material failures such as power cuts and mechanical faults. Each of these concerns exist in tension with one another, particularly in the case of concerns for the environment – with less efficient gas turbines being retained to ensure that compression capacity is maintained even in the event of a power cut, and multiple turbines being kept running even when they are not pumping gas, just so that operational resilience can be maintained[148]. Motive force is thus entangled in an array of political decisions that concern different kinds of insecurity.

Implicit within this interview extract however, are also a series of further motive forces that go beyond simple physical exertions. These forces, as Cresswell (2010) invites us to consider, involve the diverse social relations that collude to bring an entity into motion; they are the relational forces that are exerted across a network that result in particular forms of motion. Attending to motive force therefore requires us to ask *why* an entity is moving. It involves tracing out the wide network of interests that are involved in its motion, and in the case of gas, these interests include those of extraction and transportation

[148] Compressor turbines can also take up to 8 hours to overcome inertia and get up to sufficient speeds to replace other turbines if they fail, meaning that operational capacity could take a long time to return.

companies who want to produce a profit, the reliance of consumers upon gas, and the government's concerns for the gas network's environmental acceptability. Each of these interests is expressed via varying amounts of force, and these forces can affect if and how the gas can circulate. Motive force is therefore not just a matter of physics. It is relationally produced and subject to ongoing political negotiation.

Friction

Cresswell (2010) also highlights the role of frictional forces within systems of circulatory governance. These operate in direct opposition to motive forces, slowing elements down and potentially bringing them to a stop. Just like motive force however, friction can both be envisioned as a physical force, or as a more abstract set of contextual factors that provide resistance against the circulation of different entities. In its literal form, friction plays an extremely significant role in the circulation of natural gas. As the emergency operations manager describes;

"Imagine you sort of had a cardboard tube and you were putting ping pong balls in there, and that was a meter long, you would push a ping pong ball in one end and it comes out the other end. If that was a mile long, the same thing would happen, but it would be really hard to push it in. You've got to put more force, more energy, more pressure on to it at the other end of the pipeline. And eventually you going to have to put so much pressure in and...there's a limit to that. So there's only so much you can do. And that's due to the friction on the inside of the walls, the friction on the inside of that tube is essentially what drives the pressure drop. You are losing energy as it moves through the pipeline. So we will see transportation losses through all of our pipelines. Which means pressure will drop off down the pipe. So we use a compressor to raise it again. And it will drop off again, over time in due course." (Interview, Emergency Operations Manager, National Grid, 2014)

Unless additional compression therefore takes place, the frictional forces operating upon the gas would force it into stasis. As such, additional compression is required to ensure the security of gas supply. Gas therefore comes to circulate in cadences, constantly fluctuating between speeding up (and increasing in density), and slowing down (and dropping in density). In this way, literal friction becomes political through the threats that it presents to the security of supply.

If we look at friction less literally however, we can also observe other resistant forces that are operating upon the gas in this example. Perhaps most clearly, gas is subject to the frictional forces that surround the environmental impacts of its transport. Gas transport networks are under increasing pressure from government agencies to reduce their carbon emissions (created either through leakage or through using gas to power turbines), and whilst gas has been positioned as a potential interim solution for meeting the UK's carbon reduction targets as renewable generation capacity continues to be developed, recent reports regarding the unacceptably high extent of methane leakage has raised question marks over the future of natural gas transport in the UK[149]. Should natural gas's environmental impacts become considered socially unacceptable, its circulation may consequently be brought to a standstill. Furthermore, other kinds of environmentally-led development may also be seen to create impediments to gas's circulation. Improved insulation within houses and the installation of more efficient boilers, for example, have both led to an overall decline in gas consumption in the last 30 years[150]. As such, we can understand these distributed relational forces as constituting two different forms of frictional force that have different consequences for the way that security is performed around gas as it circulates.

Force(s)

Whilst I agree with Cresswell (2010) that scholars need to better attend to the politics surrounding the forces that operate upon circulations, his emphasis

[149] Interview, Health, Safety and Environment Manager, Northern Gas Networks (2014).
[150] Interview, former Network Director, Northern Gas Networks (2015).

upon motivational and frictional forces unintentionally reinforces an additional reductive notion of circulation. For Cresswell, force is imagined either in terms of a push along a particular plane, or as resistance to that vectored force. Whilst he does note that circulations move through varied vertical space, and that this affects the forms of friction that consequently act upon those circulations, he fails (perhaps due to his focus upon human movement) to adequately appreciate the presence of other kinds of forces that may be operating in different directions, at different times, and in different places. By categorising force into two binary opposing camps, he thus detracts attention from other kinds of forces that may operate upon circulations, and which may significantly affect the forms of (in)security that become associated with the gas's circulation[151].

Gas, for example, exerts varying amounts of outwards force upon pipeline walls. When they are manufactured, every pipe is allocated a maximum operating pressure at which it is allowed to transport gas. This operating pressure is designed in accordance with the outwards force that is exerted by the gas, relative to the extent to which the pipe can continue to contain it. Because different parts of the network are constructed from pipes that have different maximum operating pressures, the gas within it will therefore be transported at different pressures within different parts of the network. This has implications in terms of network constraints, for in the event of supply shortages in particular parts of these networks, gas pressures cannot always simply be raised to encourage the gas to move into areas where it is needed. Indeed, there are serious regulatory consequences for exceeding maximum operating pressures. Yet as a former engineer within British Gas's engineering research station observed, the constraining force that is provided by the pipes

[151] Not all circulating entities will be subject to the same forces, and the forces they are subject to will not always have the same political significance. Different kinds of circulation will experience various (or even the same) forces *in different ways*, within different spatio-temporal contexts, and these forces may have different political implications.

is not designed only in relation to the gas's outward force. Rather, it is designed in relation to the *combined forces* of gas's pressure and certain kinds of hypothesised external force. As he explained;

"I think certainly you can argue that [the development of standardised maximum operating pressures] was quite conservative. […] So the pipe thickness for a transmission pipeline more… (Laughs) Its not there to contain the pressure. It's there to resist somebody hitting it. So it's a lot thicker than if you just did the simple pressure calculations it would be half the thickness." (Interview, former ERS Engineer, Northern Gas Networks, 2015)

As such, these pipes are designed in acknowledgement of the multiple forces that are anticipated to potentially act upon gas circulations. This situation is also made more complex because different sections of pipeline are perceived to be subject to different kinds of threat. As such, different types of pipes may be employed to respond to them. As gas circulates near roads or urban areas for example, thicker pipes with higher maximum operating pressures are likely to be employed in order to resist the external forces that are produced by heavy traffic and ground work machinery[152].

Yet whilst some of these forces are easily traceable – as in this case, where reference to such forces was made through interviews and through entries in industry standards – there may also exist other forces that operate upon circulations that are more difficult to identify. This may be because they only present challenges in very specific situations. During one site visit for example, an engineer from Northern Gas Networks described to me how repeated reports had been made of a gas escape on a bridge in Cumbria, yet every time it was investigated, no gas could be detected. The reason for this was eventually discovered to be because of the highly specific spatio-temporal conditions that led to this escape. On sunny days, the bridge would gradually

[152] Interview, former Network Director, Northern Gas Networks (2015). Also, industry standards for transmission pipelines - (IGEM, 1995).

warm up and expand, pulling the pipes apart. Two hours later however, when the engineers would typically arrive to investigate, the bridge would have cooled down and contracted, sealing the pipe back up.

Other forces may also be hard to detect due to the way that they are governed in incredibly banal and routinized ways that have become completely normalized. A case of this regards gas's buoyancy. Because natural gas is less dense than air, it exerts an upwards force upon pipes. Under normal conditions however, this force is substantially exceeded by the downward force of the pipes' weight, combined with the weight of the earth that is piled on top of it (figure 13). Indeed, this has become so generally acknowledged that gas's buoyancy is almost entirely ignored – even in industry standards (indeed, many industry practitioners interviewed in this study were not aware of the hazards it presented). Yet, in specific cases of severe flooding when the earth around pipes is eroded, this force can present threats to the integrity of pipeline networks. When the surrounding earth is taken away and replaced by water, the buoyancy of the gas within these pipes can exert an upward force strong enough to pull them apart. Whilst extremely rare, the potential consequences of this are significant, potentially resulting in wide-scale network outages and the risk of explosions (Alderson and Finley, 2014).

In these ways, we can therefore observe a series of different forces to operate upon circulations of natural gas in different situations, and we can also identify a range of forces that the gas, itself, exerts through its circulation. As I have shown, such forces are significant for the way that we understand security's performance in relation to circulations, for they can be productive of multiple forms of (in)security that may otherwise be overlooked.

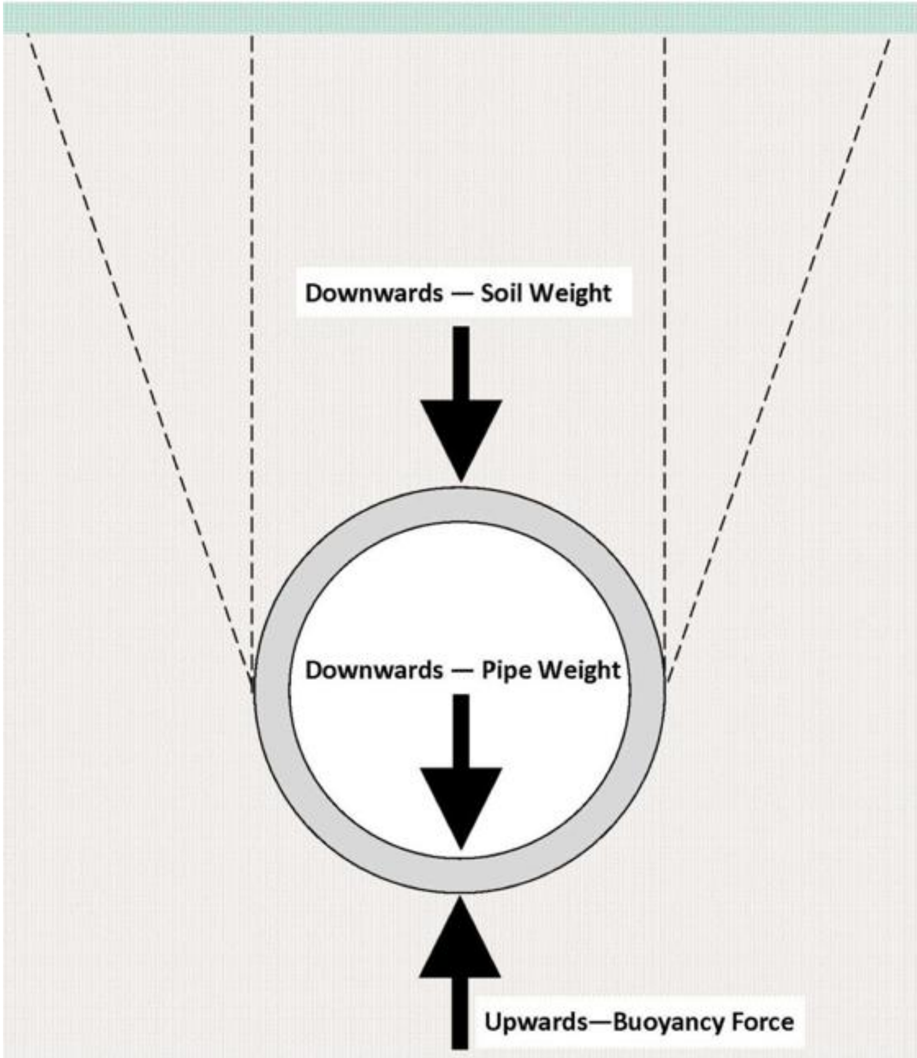

Figure 13 - Diagram of vertical forces operating on gas pipes (Alderson & Finley, 2014)

VI. Velocity

The fifth quality of circulations that I suggest has implications for security concerns velocity. As Lefebvre (2004) famously emphasised throughout his work, entities do not simply move through space: they simultaneously move through time. In order to think about circulations, we therefore need to engage not only with their spatial attributes, but also with their temporal qualities – the manners in which they move within and across time. I suggest that there are two aspects in which velocity has particular implications for security in the case of natural gas; firstly, in terms of the velocity of its movements over Cartesian space relative to other things, and secondly, in terms of the speed of its ontological movements.

Cartesian Velocity

As Cresswell (2010) recognises, the speed with which entities circulate across Cartesian space has received significant attention within the social sciences. Indeed, within security studies, speed and slowness (often discussed in relation to frictional forces) have been examined in a number of interesting ways. Numerous studies have looked at the significance of speed in performances of contemporary warfare (Virilio, 2006; Graham, 2010a; Coward, 2009); multiple authors have examined the way in which certain airport security practices permit different bodies to move at different speeds, with the movement of VIP 'safe' bodies being sped up, whilst those bodies considered riskier are slowed down (c.f. Wood and Graham, 2006; Adey, 2004; Vaughan-Williams, 2010); and Bigo (2014) has described the way in which the faster speed of data's movement, relative to that of human bodies, is central to contemporary practices of security. Multiple studies have also focused on the speed with which various kinds of security apparatus can assemble and respond in relation to the emergence of particular types of threat. Hinchliffe et al. (2013), for example, have looked at the speed of attempts to 'lock down' biosecurity threats. Adey and Anderson (2011b) have documented how attempts are made to speed up the formation of decisions in the UK emergency services, and Nat O'Grady (2014) has looked at the way in which fire services are organised across the UK in order to increase the speed with which they can move and assemble over space.

Gas is interesting in its circulation, in that the velocities with which it moves over Cartesian space are typically not a major focus within its governance. As the senior engineer from National Grid explained, "We are a pressure system so [we] will be controlling that system on pressure". Whilst velocity is related to pressure, it is only related to the differentials between pressures, not to its pressure *per se*. National Grid does have to ensure that sufficient quantities of gas are received by consumers at particular moments in time, but velocity is typically not a major requirement in this, because the NTS is typically run on a pressure surplus, through the use of what is known as 'line pack'. This means that the speed at which gas circulates throughout the system is not typically entangled within concerns for security[153].

There are a number of scenarios in which gas's velocity over Cartesian space does have implications for security, however. A good example regards the speed with which gas exits domestic appliances. Within every property that is connected to the gas network there will be a device that regulates the pressure of the gas that is exiting the system. This is important because, in order for gas to be safely burnt, its velocity has to be equal to the its burning velocity (see figure 14)[154]. A gas's burning velocity refers to the speed at which that particular chemical composition of gas burns. During controlled combustions, the direction in which the gas is burnt is opposite to the direction in which it exits the appliance. If these two velocities remain the same, then all of the gas exiting the pipe will be safely burnt, moment by moment. Should the burning velocity of the gas be exceeded by the velocity with which it exits the appliance however, then more gas than can be burnt will enter the property. In this scenario, the direction of the flame may change as substantial volumes of gas accumulate – instead of operating against the direction of the gas flow, the flame will move with it, resulting in a form of combustion that expands rapidly outwards. In other words, it will explode (figure 15). The velocity with which gas travels out of pipework is therefore directly related to the kinds of security threat that the gas poses, with increases in velocity being perceived to

[153] Site visit, National Grid House (2014).
[154] Site visit, RAF Spadeadam (2014).

potentially result in significant increases in the risk of fires and explosions. The role of pressure regulators on domestic appliances is thus to govern gas's velocity so as to 'cancel out' these particular kinds of threat.

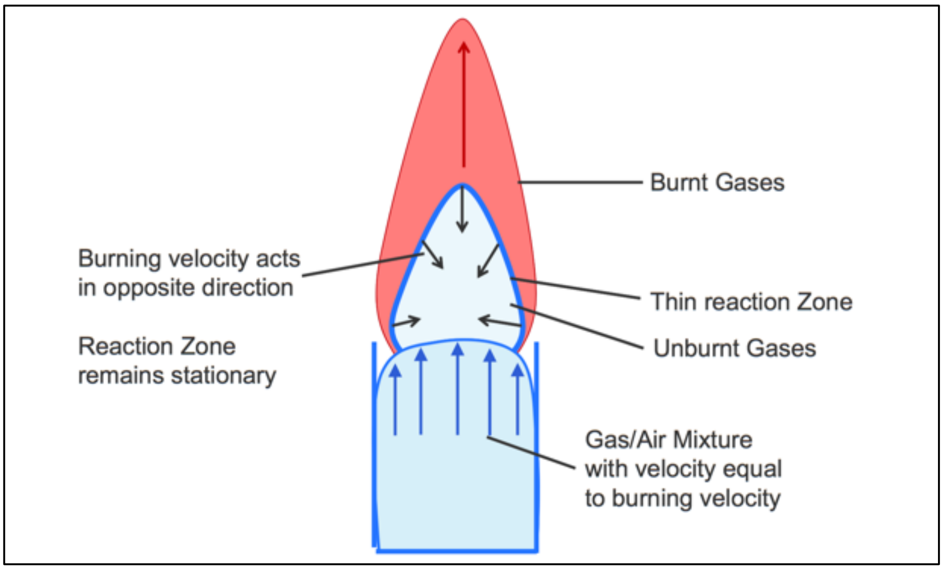

Figure 14 - Diagram of the relative velocities involved in controlled combustion (Cowling, 2014)

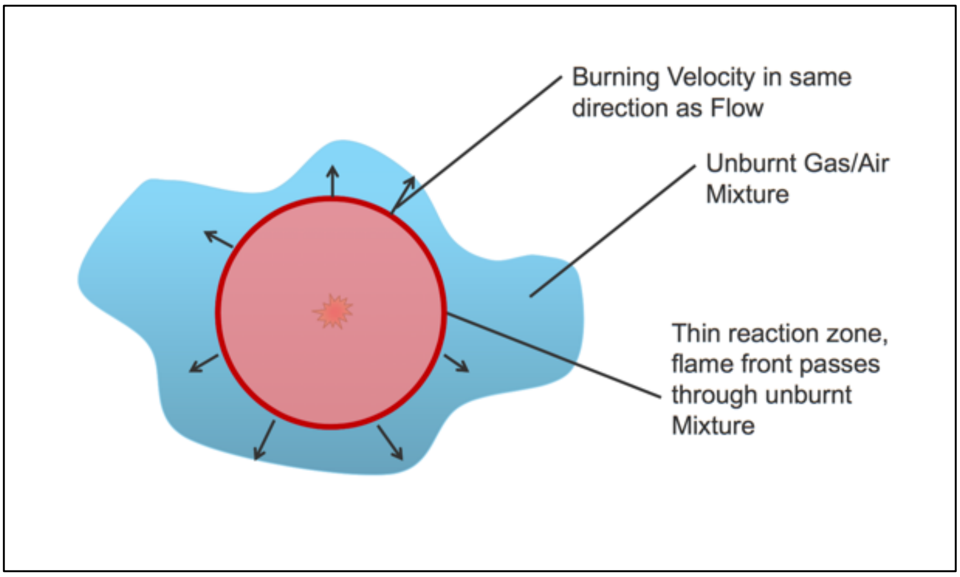

Figure 15 - Diagram of relative velocities involved in uncontrolled combustion (Cowling, 2014)

In addition to the velocity of gas's own circulations within Cartesian space, there are also many ways in which we can observe the significance of speed for responding to threats. Perhaps most clearly, speed is important in the case of the standardised response times to gas escape incidents. For uncontrolled reported escapes, emergency engineers must attend a reported escape within

1 hour, whilst for controlled escapes (where the consumer can independently shut off the flow of gas at an earlier point in the system), engineers must arrive at the scene of the leak within 2 hours. These response times are also supplemented by the Gas Safety (Management) Regulations (1996), which stipulate that all gas leaks must be repaired within 12 hours. Standardised response times such as these directly relate to the speed with which gas's governing actants assemble over space, and their purpose is to try to halt gas's escape before it realises its capacities to cause casualties and damage to property. Like all kinds of movement however, these movements also face resistance. The 12 hour repair rule implemented by the GS(M)R, for example, has caused particular controversy with network operators due to the resistance that these operators face in attempting to achieve a rapid repair. Excavating, finding and repairing leaks can be extremely time consuming, and to do this within 12 hours can be nearly impossible. As one engineer explained,

"A lot of people within the industry said no, let's not - we can make it <u>*safe*</u> *in twelve hours. We can't repair it in twelve hours. It's impossible. We've got some of them that you can't even find!" (Interview, former Network Director, Northern Gas Networks, 2015)*

In this way, we can observe the assembly of engineers around leaks to become subject to significant frictional, or resistive, forces, and these forces can result in degrees of slowness that limit the ability of governing actants to secure against emerging phenomena.

Relational Velocities

It is not just the speed and slowness of movements through Cartesian space that have implications for security, however: we must also reflect upon the temporal qualities of their movements through *relational space,* and the way that these elements shift ontologically over time. A simple example of this can be seen in the case of the oceanic circulation of liquefied natural gas (LNG) by container ship. Gas is liquefied by cooling it to below -162°C, but after its initial refrigeration, no additional cooling usually takes place (Mokhatab et al., 2013). Throughout its journey it is therefore gradually warming, and as it warms, it begins to expand and convert back into its gaseous form (Ibid). In this way, it simultaneously moves through relational space whilst also moving across Cartesian space.

The speed of this ontological transformation presents two particular challenges for its secure transportation, both of which regard human safety. The first concerns its composition, for the slower its circulatory journey, the more LNG's chemistry and energy content will be altered. As the gas gradually warms, particular chemicals within the liquid gas will evaporate before others (Dobrota, Lalić and Komar, 2013). This typically leaves a liquid mixture that is more energy-rich by volume than the liquid transported at the beginning of the journey[155]. Because the UK gas network is calibrated to use a specific chemical composition of gas that is much lower in energy however, these increases in LNG's richness would have severe safety implications if the gas were to be introduced to the NTS (the flames issuing from domestic appliances would be dangerously large)[156]. For this reason, a practice of reintroducing nitrogen into the LNG is employed within LNG reception terminals in order to govern the flammable agency of the LNG as it is converted back into gas.

The second challenge regards LNG's expansion. As it warms and evaporates, LNG also expands, creating a vast amount of pressure. Unless the expanding gases are released, the pressure within LNG tankers could severely threaten their integrity. As such, efforts are taken to govern the speed of gas's relational changes whilst it is in transport, and such efforts consist of attempts to speed

[155] This is because nitrogen, which is inert, is one of the first materials to evaporate.
[156] Interview, former Network Director, Northern Gas Networks (2015).

up gas's Cartesian movement by reducing its processing and transportation times. The purpose of these efforts is to limit the amount of ontological change that gas can undergo during its journey. They also involve attempts to directly slow down the speed of gas's ontological transformation, which is achieved through the use of enhanced insulation techniques that reduce the rate with which gas warms and expands. In these two ways, the speed of gas's movement within relational space therefore becomes tightly enmeshed with particular concerns for security.

In these three ways – the speed with which gas circulates over Cartesian space, the speed with which its governing actors react and (re)assemble over Cartesian space, and the speed with which the gas changes ontologically – we can see velocity to play and important role in the forms of insecurity that emerge in relation to gas's circulation, and in the forms of security practice that are consequently employed to govern it.

VII. Rhythms

The final circulatory quality of natural gas that I want to highlight here regards the rhythms with which gas circulates. As Cresswell (2010) observes, various kinds of rhythmic movement can produce different kinds of political effect – from enabling the identification of risky passengers through gait analysis, to the association of the rhythms of rave music with certain kinds of socially deviant behaviour. This is the extent of Cresswell's analysis of rhythmic movements in relation to governance however, and limited attention has been paid to their significance for performances of security elsewhere. The following paragraphs therefore expand upon some of the implications that gaseous rhythms may have for security.

According to Lefebvre (2004), nothing is inert; all things in the world are in motion within time and space, and all of these movements have different rhythms (repeated moments of movement and rest) that have different degrees of social significance, dependent upon their relation to other societal rhythms. Lefebvre's perspective consequently invites us to consider a social world that, rather than being fixed within a singular and uniformly experienced social time, is characterised by a plurality of rhythms and experiences of time; it consists of a 'polyrhythmic ensemble' (Crang, 2000).

Gas circulations are similarly characterised by repeated moments of movement and rest, acceleration and deceleration. Gas speeds up at point of compression, and slows down over time because of friction. It moves with seasonal rhythms – with increased volumes flowing over cold winter months and lower volumes over the summer period. It circulates with diurnal patterns, with increased movement as demand increases during the mornings, late afternoons and evenings, and at night its movement decreases, as demand reduces and the system is 'line-packed' to provide storage for the following day[157]. As such, gas's rhythmic circulations can be seen to be closely associated with other societal rhythms, and in particular, with the rhythms of the human body. Indeed, seasonal and diurnal patterns are directly related to the rhythms of human social life, because gas is consumed largely in line with patterns of bodily thermal comfort, sleep and hunger. There is thus a close synchrony between the circulation of natural gas and the rhythms of the human body.

It is through these countless rhythmic movements, the coming together of different materials, bodies and things over time that the social world is performed. Place is "always in a process of becoming", and the rhythmic patterns with which these entities come together structures "the ongoing

[157] Interview, Emergency Operations Manager, National Grid (2014).

formation of its materiality" (Edensor, 2010; 3). It is therefore by coming to terms with this continual performance of place that we can begin to understand the relationship between security and spatio-temporal movement. Whilst, as Edensor notes, these rhythms can bring stability and consistency to the becoming of place, within these rhythms there is always potential for creativity, change or disruption. Repetition, whilst being a defining feature of rhythms, does not preclude difference or the potential for change – rhythm is not fixed (Mels, 2004): it is performed, and these performances require effort (Hallam and Ingold, 2007), always holding within them "the immanent potential for disruption and destruction" (Edensor, 2010; 3). Insecurity is consequently inherent within the rhythmic performance of place.

The relationships between different kinds of rhythm are of critical importance for Lefebvre, for it is through tensions in these relationships that he understands insecurities to arise. Lefebvre describes the emergence of insecurity through the concept of arrhythmia. Arrhythmia concerns the way particular rhythms fall out of attunement with one another or become dissonant. This can constitute a form of pathological failure; a process of 'fatal de-synchronisation' (p.78). In contrast, security can be seen to be produced through particular kinds of harmonious eurhythmia; the creation of synchrony between societal rhythms.

I suggest that the practice of synchronisation constitutes a form of circulatory governance. Considerable effort is expended upon manipulating the temporal qualities of gas circulations to prevent arrhythmia, and this can perhaps best be seen in the practice of gas day forecasting. Attempts are made to anticipate the annual, seasonal and diurnal rhythms of societal demand for gas, and based upon these figures, a distributed assemblage of actors work to adjust gas's rhythms accordingly. National Grid is the organisation responsible for forecasting rhythms in demand for gas in the UK, and this information is then used to inform the daily operational decisions of a distributed network of actors within the gas industry that includes producers, shippers, service operators, storage operators, large energy users and government. Forecasts are the primary means by which the rhythms with which gas is bought and sold, stored, compressed and transported are managed. The projection of rhythms of demand is therefore a key aspect of gas governance, with a multitude of actions being undertaken upon them[158].

Projecting demand rhythms is a complicated task however, primarily because demand is not just characterised by a single rhythm. Instead, it is constituted by a multiplicity of rhythmic movements that have to be taken into consideration in order to produce accurate forecasts. Broadly, these rhythms can be broken into five groups: industrial rhythms; the rhythms of local distribution zones; the operational rhythms of power stations; the rhythms of interconnectors; and the rhythms of storage. Each of these rhythms is made up of many smaller rhythmic movements that result in very different overall characteristics and unique challenges for prediction. Rather than examine each of these in detail here, I want to take a brief look at the way that distribution network demand is forecast, and demonstrate how a vast multiplicity of rhythms come into play in performances of synchronic security.

Synchronic Security

Demand in local distribution zones is difficult to forecast. It is made up of the daily rhythms of the millions of people that inhabit wide regional areas and who use gas within their houses, offices, schools, retail centres, small businesses, and hospitals. These rhythms are in turn largely dependent upon these people's bodily rhythms; their patterns of hunger, thermal comfort and

[158] Interview, Demand Forecaster, National Grid (2015).

sleep. In order to predict demand, National Grid tries to find patterns in the daily consumption routines of people living in different distribution zones. The rhythms of when people get up, leave for work, return home, cook food, and go to sleep, influence the daily recorded gas demand, but they do not sufficiently explain the volatile rhythms that National Grid observes. This is primarily because the main domestic use of gas is for thermal comfort. The bodily rhythms that drive demand are thus also dependent upon meteorological rhythms – the rhythms of precipitation, temperature and wind chill for different areas around the country. National Grid therefore also collects weather data from more than twenty sites that are located across the UK's distribution zones, and then uses this data to create a composite weather variable (CWV) that combines projected weather conditions with typical daily consumption patterns.

Whilst this creates an improved rhythmic projection however, it still doesn't adequately account for the observed demand behaviours. This is because consumer behaviour also contains a psychological component. When it is raining or unpleasant outside (but not necessarily cold), consumers will often still turn on their heating, particularly during transitions between hot and cold seasons. National Grid have consequently designed their CWV to take into consideration additional meteorological factors such as daylight levels, fog, mist, time of year, and their predicted psychological impacts. The result is a composite variable that mirrors rhythmic patterns in daily consumer demand with a high degree of accuracy (see figure 16).

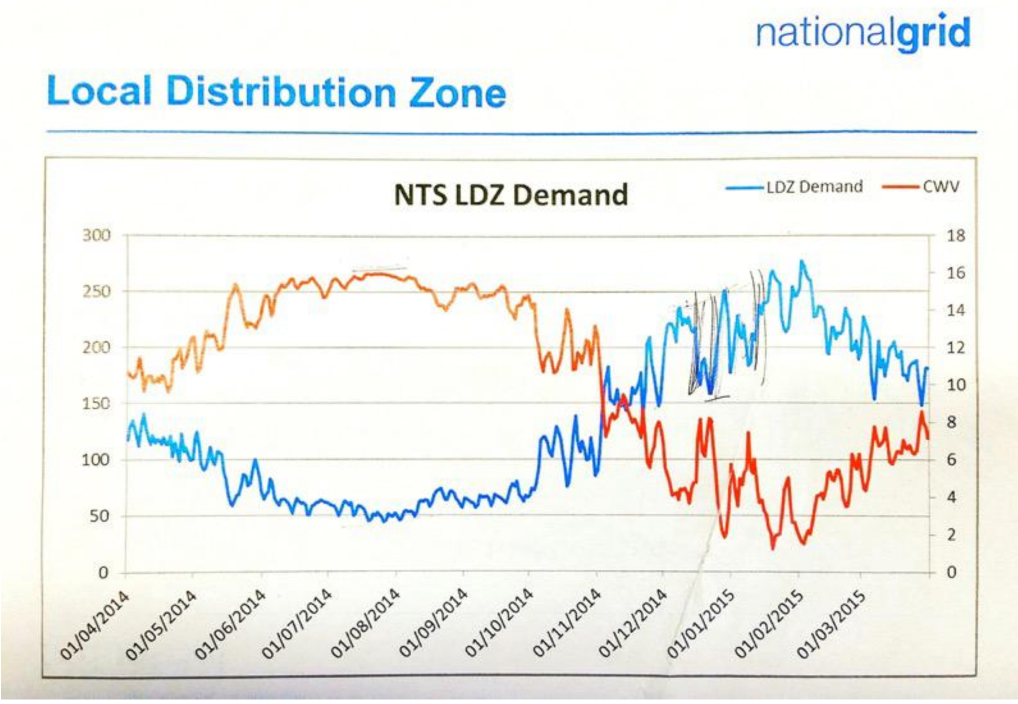

Figure 16 - Graph of consumer demand relative to forecasts(National Grid, 2015)

As such, we can see in the case of National Grid's demand forecasting for local distribution zones an attempt to draw together multiple rhythms that are external to the rhythms of gas in an effort to synchronise gas's circulations with them. Such attempts, I suggest, can be seen to be premised upon concerns for security, for it is the phenomena of the fatal arrhythmia of demand and supply rhythms that these practices seek to 'cancel out'.

VIII. Conclusion: Beyond Lines

In this chapter, I set out to challenge the way that circulation has typically been framed within the critical security studies and energy security literatures. I set out to challenge how circulation often appears as direct, linear, unproblematic and boring: as inconsequential movements of 'stuff' that only require attention at periodic 'check points' across their journeys. In confronting this premise, I pursued one of the central agendas of this thesis; to examine the way that different forms of (in)security become entangled with circulations across their journeys, as they move *between* nodal points.

I took the example of the pipeline – the seemingly quintessential model for modernist circulation – and made it strange. Building upon the work of Timothy Cresswell (2010), I highlighted six qualities of gaseous circulations that have received little attention within the existing security literatures. Each of these qualities was then shown to have important implications for the emergence of different forms of insecurity, opportunity and security practice.

The first of these qualities regarded the implications that the circulatory paths of different elements have for security. In section II, I explored the way that these paths are often far from linear and featureless, but can be rhizomatic and textured, and, in the case of gas, are not necessarily one-directional. Instead, natural gas was shown to travel back and forth within pipelines of different sizes and materials, introducing it to new forms of external actor that it could forms of hazardous relation with. Indeed, even when its movements *were* relatively linear and direct, I demonstrated how this linearity must be appreciated for the ways in which it produces different forms of (in)security – in this case, simultaneously enabling new forms of surveillance but also introducing critical vulnerabilities to sabotage and accidental damage.

Also in this section, I described how we might valuably attend to the circular aspect of gas's circulation. Rather than limit analyses of circulations to simply the travels between two nodal points, I described how gas's points of production, consumption and escape are widely dispersed and may not be easily identifiable. I also suggested various way that we might understand gas's journeys beyond these points to be productive of forms of (in)security.

The second of gas's circulatory qualities explored here regarded its volume. In section III, I traced three ways in which volume can be understood in relation to the securing of circulations of natural gas. First, I described how gas circulates through voluminous space, demonstrating how it becomes implicated in various concerns for security as it travels at different altitudes. Second, I described how the gas can be understood as voluminous in terms of the quantity of molecules that are contained within its circulation, demonstrating how this quantity was the implicit focus of analyses of the security of supply and demand. Third, I described how we must appreciate the three-dimensional volume of circulations, outlining how this can have implications for the commercial viability of gas's sale and overseas transport.

In section IV, I then briefly examined some of the material qualities of natural gas and the way that they can be seen to become entangled with concerns for security across its journeys. Whilst other aspects of this entanglement form the focus of other of this thesis's empirical chapters, in this section I identified three qualities that have particular significance for the forms of (in)security that arise across gas's circulatory journeys. These were; its appearance, its mutability, and its textures.

In section V, I then examined a number of forces that are exerted upon gas across its circulations. I began by describing two forceful features of these circulations – motive force and frictional force – that have been previously analysed for their political significance in the mobilities literature, but are yet to be meaningfully attended to in critical security studies, or energy security literatures. I demonstrated how these forces are implicated in a number of concerns for security, both in terms of the physical exertions that can be observed in the case of compression, or the frictional forces that are provided by the pipe walls (both of which can be seen to be connected to concerns for the security of supply), and also in terms of the networked forces that facilitate and resist the gas's continued movement. Moreover, in addition to these motive and frictional forces, I drew attention to a series of other forces that can be seen to operate upon gas circulations – and which these circulations exert – that are similarly productive of (in)securities in different ways.

In section VI, I turned to examine the temporal qualities of gas circulations, with a specific focus on the significance of velocity for performances of gaseous security. I described how there are a number of instances in which the speed (or slowness) with which gas moves has significance for the way that security is performed. In particular, I drew attention to two forms of velocity; the speed of its movements across Cartesian space, and the speed of its movements across relational space.

Finally, in section VII, I explored the way that gas's circulations must be appreciated for their rhythms. I described how these rhythms become wrapped up in concerns for security through the practice of demand forecasting. Here, I drew upon Lefebvre (2004) to draw attention to a practice of synchronic security, whereby attempts are made to match the rhythms of gas's circulation with the complex rhythms of consumer demand. Failure to achieve this synchrony was perceived to result in a form of 'fatal arrhythmia' (Ibid), whereby societal rhythms became disconnected from the rhythms of the gas, leading to the disruption of everyday life.

In these different ways, I have therefore demonstrated how gas's circulations are far from simple trajectories between nodes. Such circulations have myriad qualities that present diverse challenges and opportunities for performances of security. By acknowledging these qualities and their implications, we are forced to recognise the distribution of security's practice along the extents of elements' circulatory journeys. As such, security is not something that is simply practiced at nodally specific sites; it is a continual performance that is conducted across the length and breadth of elements' travels. It is to the specifics of these security performances that I now turn in the final empirical chapter.

6

Circulation, Mutation, and Modular Performances of Security

"There is nothing in the world that remains unchanged. All things are in a perpetual state of flux, and every shadow is seen to move"
(Ovid, Metamorphoses, book XV)

Gas, n.1
'A substance in a state in which it expands freely to fill the whole of a container, having no fixed shape (unlike a solid), and no fixed volume (unlike a liquid)'
(Oxford English Dictionary, 2015)

I. Introduction

In the UK's natural gas infrastructure, a small fluctuation in gas's calorific value (CV) can have wide-ranging impacts. Decreases in CV can lead to appliances burning the gas inefficiently, resulting in the production of carbon monoxide and the potential poisoning of domestic consumers. Increases in CV could lead to the exaggeration of flames from domestic and industrial appliances, resulting in fire hazards and threats to public health. Such increases may also elevate the explosion risk associated with the transport of gas, with lower volumes needing to escape before a potentially explosive atmosphere develops. Gas's calorific value is therefore carefully regulated throughout the UK's natural gas transport network, with a complex set of monitoring and securing practices constantly employed to prevent the gas from deviating from an exacting chemical specification.

The case of CV regulation is just one example of how gas's mutability has become incorporated within a system of governance. Natural gas is an inherently protean material that throughout its circulation will undergo a series of dramatic alterations. At different locations and times, it will become denser and less dense; it will expand and contract; it will wildly fluctuate in temperature; it will change state (from gas to liquid, and liquid to gas); it will contain more and less water, and it will shift in its chemical composition in other ways than just its energy content[159]. Added to these changes, it will also move with manifold rhythms and velocities, change its direction of travel in three-dimensional space, and throughout its journey, develop various, contingent relationships with a wide variety of other materials, bodies and things. Gas circulations are thus never fixed or uniform; they undergo constant change, mutating from moment to moment.

These transformations need to be appreciated for their different relationships with security's performance. Indeed, gas's mutation can have important implications for the different forms of danger and opportunity it is perceived to present, and it can affect the way that security is consequently performed in relation to it. From increases in gas's pressure that cause it to exert greater force upon pipe walls, to the way that gas forms new relations with multiple human bodies as it travels within high-rise buildings (and consequently develops the capacity to cause mass casualties), each new relational mutation produces fresh forms of agency and opens up new potential gaseous futures that systems of governance attempt to form around.

[159] At different times, for example, it will include and exclude various toxic materials such as hydrogen sulfide, carbon monoxide, and carcinogenic dust.

Yet whilst the mutability of elements[160] has significant implications for the ways that security is performed, it has been almost entirely overlooked in the critical security studies and energy security literatures. Indeed, whilst these literatures have extensively explored security's performance in relation to a wide range of circulating entities, scholars have tended to assume that the bodies, objects and things under study rigidly hold their shape and qualities throughout the duration of their transit, and that the performances of security conducted upon them remain relatively constant[161].

I suggest that this oversight is symptomatic of the way that performances of security have typically been reduced to two kinds of practice through which circulating elements pass, but are not deformed. The first of these practices might be described as *circulatory filtration*. Considerable effort has been expended in the critical security studies literature on describing the various means through which risky circulating entities come to be 'bordered' – how they are systematically separated from other entities in circulation that are considered to be safe. As a result, we now have at our disposal a wide variety of studies that have examined filtration practices in relation to such diverse circulatory figures as the terrorist (Adey, 2004; Amoore, 2007; Amoore and Hall, 2009; Aradau and van Munster, 2008; Vaughan-Williams, 2007); the 'illegal' immigrant (Coleman, 2005; Rossmo et al., 2008; Amoore, 2006); the

[160] Mutability is not exclusive to gas. As Pete Adey (2006) reminds us, some entities may be more durable than others, but all are ultimately transient and are prone to change.

[161] There has been some valuable research in other fields that has emphasised the transformative qualities of circulating elements. In particular, I refer to the work currently being conducted on circular economies (Gregson et al., 2015; Hobson, 2015; Kama, 2015), whereby the material transformation of entities and the ways in which they are subsequently valued are traced out and documented. Relevant research has also been undertaken within the literature on food geographies, with several historical accounts usefully documenting a range of technological developments in practices of circulatory governance, most notably with regards to the management of the decay (Nimmo, 2011; Twilley, 2014; Dunn, 2011; Atkins, 2004, 2011, 2010). Finally, the recent (mainly geographical) work on dynamic mobilities and fluidities has valuable utility for conceptualising the political significance of shifting movements (Cresswell, 2010; Steinberg and Peters, 2015; Cresswell and Martin, 2012). Despite these avenues of enquiry however, little work has acknowledged the relevance of such transformations for performances of security.

asylum seeker (Devetak, 2004; Rajaram, 2008; Buckel and Wissel, 2010); the risky financial transaction (Goede, 2006; de Goede, 2007; Favarel-Garrigues, et al. 2011); the diseased body (Hinchliffe and Bingham, 2008; Hinchliffe et al., 2013; Clark, 2013b) and the illicit narcotic (Ackleson, 2005; Bourne, 2015). Yet within each of these studies, there appears to be an assumption that, as their elements of concern pass through these nodes, they either simply come to a stop, or are allowed to continue. Little attention is paid to what happens to apprehended elements, or to how their threatening agency is addressed, compensated for, or 'cancelled out'.

The second practice can be described as *circulatory maintenance*. This features in both the critical security studies and energy security literatures, but it is most prominent in the latter[162]. Indeed, circulatory maintenance is *the* primary narrative of security's practice in relation to energy (c.f. El Badri, 2008; Cornell, 2009; Sovacool and Brown, 2010; Yergin, 2006; Bradshaw, 2009), insecurity being seen to stem from interruptions to energy's circulation, and security featuring as a set of largely economic and political practices through which the continued circulation of energy products is maintained. Again, no attention is paid to how energy (or any other form of circulating element) is transformed through this practice, nor is attention paid to how the dynamic material qualities of the things in motion may trouble the way that their circulations are maintained.

As such, within both of these narratives, elements are presented as being passive, unproblematic, and entirely immutable. In this chapter, I seek to provide a counter-narrative to this discourse. I argue that an attention to the dynamic vitality of natural gas and its mutability is necessary for understanding

[162] For examples of narratives of circulatory maintenance in the critical security studies literature, see the work of Cowen (2009, 2010) that looks at the implications of frictional forces upon the transport of cargo, and the work Langley (2014), who has examined economic security in terms of the necessity of the continued circulation of finance.

the challenges that elements (bodies, materials, things) present for their governance, and for appreciating how security involves practices of relational organisation through which particular forms of gaseous phenomena come to be facilitated, compensated for, or cancelled out. Security, as I conceptualize it here, thus far exceeds simple practices of filtration or maintenance. It is an *ontological project*[163].

I pursue this argument in the following way. In section II, I provide a discussion of how we might conceptualise the mutation of circulating entities. I describe how mutations open up new forms of actual and potential agency (including new forms of mobility), and I draw upon the work of Foucault (2007) and (DeLanda, 2006) to demonstrate how we might recognise security as constituting a set of practices of relational organisation through which particular forms of gaseous phenomena come to be facilitated, compensated for, or cancelled out.

In sections III and IV, I then turn to provide an analysis of the specific ways in which these relations are organised in the case of natural gas. In each section, I take a different point in gas's journey within the UK's transmission and distribution systems, and describe how specialized security apparatuses have been developed around the gas at these points to (re)arrange its relational configuration in different ways, according to the interests of the actors involved with it at these particular locations.

From these analyses, I suggest that we can observe five specific techniques through which gas's ontological structure comes to be rearranged: the distancing of exterior relations, the formation of relational 'blocks', the transformation of relations of interiority, the reinforcement of relations, and the

[163] Or series of ontological projects.

formation of indicative relations. By examining these various practices, I suggest that mutation must be seen as being central to performances of circulatory security.

In section V, I then conclude by proposing that we understand such security performances through Deleuze's (1992) concept of modulation, whereby assemblages of security actors orbit circulations, performing them as secure at different points in space and time by manipulating their relational arrangements. Such an approach, I suggest, may provide a means through which to better appreciate the dynamism of elements and the way that security is differentially (and dynamically) performed across entities' circulatory journeys.

II. Mutation and Security

Mutation can be seen to create problems for security primarily through the new forms of possible agency[164] and gaseous phenomena that it brings into existence. As I discussed in Chapter 5, the work of DeLanda (2006) can help us to understand an elements agency as being the emergent product of its specific configuration of interior and exterior relations. Relations of interiority are the sets of relations that exist between an entity's internalised elements, and these define its inherent capacities to act in different ways. Relations of

[164] Material agency is a controversial topic within security debates. In this chapter, agency is considered as "*a matter of intra-acting; it is an enactment, not something that someone or something has*" (Barad 2007; 178). This intra-action can occur between materials, bodies and 'things', meaning that agency is not aligned with human intentionality: it is an emergent phenomenon that is not exclusive to either human bodies or to materials. Material agency is therefore not fetishized in this account (I am not a vital materialist, nor am I a post humanist in the typical sense of the term). Instead, matter and human bodies, following Latour (1993), are assumed - at least in the first instance - to have equal capacities to act. This is important for security, for as Barad notes, "Holding the category 'human' ('nonhuman') fixed (or at least presuming that one can) excludes an entire range of possibilities in advance" (2007; 178), and these possibilities must be seen to be constitutive of the phenomena that security seeks to map out and govern against.

exteriority are then the relations that exist between that element and other elements external to it. It is through the formation of particular relations of exteriority with other external elements that elements may actualise their inherent capacities to 'act', with certain forms of related phenomena coming to emerge in the process. Without the actualisation of these relations however, such capacities will remain latent, or virtual.

I understand mutation to involve the configuration of these sets of internal and external relations shifting as elements move through space and time. Internal changes may occur through the inclusion or exclusion of internal components (such as in the case of natural gas flows acquiring rust particulates as they flow through corroding pipes, or gas having its hydrogen sulphide molecules removed in processing terminals). They may also occur through alterations in the relationships between these constitutive parts, as in the case of gas's pressurization, through which it experiences shifts in the distance between the molecules that constitute it, and the way that their atoms vibrate. Shifts in relations of interiority can be extremely significant for the governance of circulating elements, for they can affect their irreducible properties and the constellation of virtuals that surround them. As a result, new capacities and potential futures open up that can become actualised.

Whilst an entity's constellations of virtuals, and therefore its latent capacities, are dependent upon these internal relations, the external relations of elements can also shift through changes in their surrounding milieus. This is particularly the case for elements that circulate widely across space and time, for their journeys draw them into constantly unfolding combinations of associations. As particular sets of relations come into being (or actualise from their virtuality) during these travels, so elements may realise particular forms of agency that have previously remained latent. In the case of gas, it comes into the proximity of, and consequently forms external relations with, a wide variety of other elements as it circulates. Whilst these relationships may often be transient and fleeting, they can be sufficient for certain gaseous capacities to become actualised.

This movement and the shifting of relations that it results in should not be regarded as 'other' to the relational construction of elements, however. Movement itself must be seen as a relational effect that results from the way that force is distributed within these relational configurations. Such forces may take more traditional forms, such as the motive force that is exerted upon gas flows by compressor turbines, but they can also be understood in a more Foucauldian sense – to include generative forces such as those that are applied through the political, economic and social relations that continue to necessitate and legitimise the extraction and transport of natural gas. Mobility is thus a product of complex webs of socio-material relations that may also undergo change.

Building upon the observations outlined in the previous chapter, if we are to understand movements as emergent phenomena that result from the actualisation of particular sets of relations, then we must also acknowledge that there may be many different kinds of movements that exist in their virtuality, and that beyond these movements will reside immense arrays of further virtual relations. As has been discussed earlier, this can have implications for security's performance, as the emergent movements of entities may provide them with the capacity to produce undesirable destabilising effects.

Taking this approach, no element can be considered inherently stable or ontologically fixed. The gas in this study appears as a shape-shifter, a perpetual transformer; a traveller that is forever in the midst of metamorphosis. Its relations of interiority and exteriority warp as it moves through space and time, transforming it ontologically and altering its properties, qualities, movements, and the kinds of agency that are available to it. New gaseous actualities emerge, fresh constellations of virtuals branch out, and new potential futures erupt forth.

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Bringing DeLanda's (2006) ideas on the relational construction of emergent wholes into conversation with Foucault's (2007) work on the governance of food scarcity can help us to develop a better understanding of the way that security and mutation are closely entwined. In his brief description of the way that circulations of grain are governed through a security apparatus, Foucault usefully draws our attention to the way that the whole lifecycle of grain becomes incorporated into the practice of security. From seed to consumption, grain passes through multiple hands, comes into contact with numerous materials, and circulates within a range of different environments. At each stage of its journey, the various elements that it comes into contact with exert themselves upon it according to their different interests, and come together to form an apparatus of security that manages its movement and compensates for, or cancels out, particular kinds of phenomena.

Yet whilst Foucault's account refers specifically to the management of the circulation of a material element, he is exceptionally brief in his analysis of the specific kinds of actions that are taken upon it, and about how the grain is transformed through the process. This, as Barad (2007) notes, is characteristic of Foucault, who exhibits a tendency to focus "on the production of human bodies, to the exclusion of nonhuman bodies whose constitution he takes for granted" (p. 169). As such, the material drops out of Foucault's accounts, and he consequently overlooks certain important aspects of the mechanics of security performances, and the way that the constitution of bodies and materials is managed through practices of security. In this chapter I attempt to address this absence by focussing specifically upon the relational constitution of materials, and by drawing upon DeLanda's concepts of relations of interiority and exteriority in order to do so.

For Foucault, the securing of circulating elements takes place through the governance of their realities. It is upon these realities that security apparatuses are grafted, and it is upon these realities that "[security] tries to get a hold" (2007; p36). For DeLanda, a whole's reality emerges through the actualisation of its relations of interiority and exteriority. It comes into being through the ongoing development of different kinds of relations between heterogeneous elements. Reality thus emerges through the realisation of these relations; through their 'becoming reality'. It must therefore be seen to consist of complex assemblages of realised relations of interiority and exteriority. As Barad puts it, "reality is composed […] of things-in-phenomena" (2007: 140); realised 'things', or 'phenomena' that are in the process of forming.

This ongoing process of formation also draws attention to the vast series of other virtualised relations that lie beyond the relations that are currently actualised, however. Reality, in a given moment, is always linked to a proliferation of other potential realities that could (but may never) form. It is the governance of the process of relational formation, the management of which relations become real, and which remain virtual, that I argue is the focus of security. Security seeks to manage different entities' relations so that those configurations that are perceived to constitute particular kinds of threatening phenomena can be "gradually compensated for, checked, finally limited, and, in the final degree, cancelled out" (Foucault 2007; 37), and so that, I argue, other *desirable* relational formations might be facilitated. As such, security must be seen as an organisational project through which attempts are made to grapple with and manage the realities of circulating entities – to manage their ontologies – through strategically arranging their relations of interiority and exteriority as they move through space and time.

As security scholars we consequently need to pay close attention to the relations of exteriority and interiority that constitute the entities of our enquiries. This is a difficult task, for as DeLanda (2006) notes, the complexity, transience, and potential imperceptibility of these relations means that it is never possible to exhaustively trace them. Whilst our analyses may never be complete however (and indeed, we would never know if they were), attempting to trace these relations is not a fruitless task, but one that can yield valuable insights into the operations of security and the ways in which circulating entities come to be perceived as the sources of potential opportunities and threats. As such, Foucault recommends that we should try to observe the points at which security actants "connect[…] up with the very reality of […] fluctuations" (2007; 37). By attempting to hold the circulating entity firmly within our analytical sights, we can endeavour to observe the relationships that different actants form with it, to document the kinds of action that they undertake upon its relations of interiority and exteriority, and to investigate the types of logic and interests that drive the formation of these connections.

III. Securing Natural Gas (I): Latitude

So what does the operation of security in relation to the circulation of natural gas look like when we take this approach? What forms of securing action are undertaken upon the gas, and what logics inspire these actions? In order to examine these questions, I begin my analysis with an example, tracing out some of the connections that converge upon gas at a single location in space and time. By taking such a latitudinal, cross-sectional 'slice' through the pipeline in this example, and by tracing the webs of relations that propagate forth from the gas, I believe that we can reveal a variety of security practices that are employed to structure its reality.

The example chosen here is the gas in the pipe in figure 17. In this image (which was taken near Bacton in Norfolk), a signpost indicates the presence of a section of NTS pipeline. The gas travelling through this pipe flows in large volumes at high pressure (up to 85bar[165]), and its molecules are consequently tightly packed. This causes a large amount of gas to occupy the space within the pipe, and also results in the gas exerting considerable force upon the pipeline walls. Amongst other forms of potential phenomena that could emerge from this particular configuration of gas's relations of interiority, two kinds of particularly violent gaseous capacity develop – the ability of the gas to cause large jet fires and the ability to cause vapour cloud explosions. At this singular point in its transit, it is consequently possible to observe a complex set of organisational practices that are applied to the gas's interior and exterior relations in an attempt to 'compensate for', or 'cancel out', these forms of potentially life-threatening phenomena.

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[165] 'Bar' is a unit of pressure (1 bar roughly equals the earth's atmospheric pressure at sea level). Most NTS pipelines operate at pressures up to 85bar, whilst regional gas networks pipe gas at a range of pressure tiers. Local transmission pipes transport gas at pressures up to 38 bar, intermediate pressure distribution networks transport gas at pressures between 2 and 7 bar, medium pressure distribution pipelines transport gas at pressures between 75millibar to 2 bar, and low pressure distribution pipes transport gas at any pressure below 75 millibar. 1 bar = 1000 millibar.

Figure 17 - Photograph of NTS pipeline marker in Norfolk, 2014

Perhaps the simplest practice of relational organisation observable here involves: _1) the strategic distancing of gas's proximate external relations across both time and space_. This can most easily be seen in the deployment of land-use zoning practices around gas pipelines. When first installed, the pipe in figure 17 was distanced from areas of dense development so that the likelihood of it forming external relations with properties and bodies would be reduced[166]. This action alone was not sufficient to prevent gas from forming external relations with human bodies and properties in the future however, for subsequent developments may be initiated around the pipeline at a later date. In recognition of this, the UK's Health and Safety Executive also attempts to manage the future milieus of high pressure gas installations through practices of land-use zoning. This involves providing Local Planning Authorities (LPA)

[166] Industry standards (IGEM, 1995).

with maps that divide the land surrounding high pressure gas pipelines into three zones (inner, middle, outer), based upon the results of a Quantitative Risk Analysis (HSE, 2016). In this manner, the risk of gas forming the sets of relations necessary for it to realise its capacity to take life is calculated, as is the spatial dispersion of these risks. Each zone indicates a different level of risk, and such categorizations are then used to influence the LPA's decisions as to what kinds of future development should be permitted within certain vicinities of the circulating gas.

Typically, Local Planning Authorities do not authorise developments to be built within the zone of highest risk (<10 chances per million, per year), but in the middle (<1 chance per million, per year) and outer zones (<0.3 chances per million, per year), certain kinds of development may sometimes be permitted (HSE, 2016). Authorisation for such developments is dependent upon the degree of their perceived sensitivity – a measure that is developed through the consideration of the number of people who will use the planned development, the amount of time they will be present in the property over a 24-hour period, and their relative mobility (Ibid). The greater the number of people spending a longer amount of time in a particular space, the higher the sensitivity rating that that development will receive. Those sites, such as hospitals, where users may have reduced mobility (and therefore cannot easily evacuate an area in the event of an incident) will also receive a higher sensitivity score (Ibid).

In this way, the HSE and Local Planning Authorities are involved in a practice of actively arranging gas's relations of exteriority to strategically distance certain kinds of external entity from the gas so that particular relational configurations cannot easily become actualised. Such distancing takes place not simply over space (such as when human bodies are physically distanced from gas so that their ability to form such relations is inhibited), but also over time. Decisions over the authorization of new developments are made through the calculation of the risk of gas actualizing particular hazardous relations, relative to the amount of time that a space is likely to be occupied by individual bodies. Likewise, assessments based upon occupant's mobility take into consideration the formation of external relations over both time and space simultaneously – in them, attempts are made to discern whether occupants could navigate space sufficiently quickly to distance themselves from the gas before it formed life-threatening relations of exteriority with them.

Such distancing practices involve the drawing of a line through gas's virtual cosmos, whereby acceptable gaseous realities are separated from those that are deemed to be unacceptable. By ordering gas's proximate external relations across time and space, an attempt is thus made to exclude gas's unacceptable realities and to relegate these relations to virtuality. In this way, particular kinds of gaseous agency come to be limited, inhibiting the emergence of life-threatening phenomena. This does not entail an absolute eradication of the phenomena however, for these relations will always continue to exist in their virtuality. As such, gas's potential agency is not annihilated, but simply inhibited. This is also not a permanent situation, for it involves a performance that is always open to transformation or failure, and which maintains the possibility of these relations becoming actualised.

Hazardous phenomena are also never completely eradicated because a compromise has to be made between individual safeties on the one hand, and on the other, the need for subsequent developments on surrounding land. Along the length of the NTS, bodies and buildings are not always distributed so that they sit totally beyond gas's relational grasp. Despite the identification of risk, the actual development of property within the proximity of pipelines is conducted at the discretion of the Local Planning Authority, and as such, development occurs according to what Foucault (2007) terms a 'bandwidth of the acceptable' (p. 6). Instead of a precise incision, or absolute boundary, being drawn between acceptable and unacceptable distances of people and property in space and time, a principle of risk is employed, whereby the likelihood of these relations actualising out of their virtuality is calculated, and the acceptability of these risks assessed. Whilst in an ideal scenario, bodies and buildings would be arranged so that they were sufficiently removed from gas's proximity to ensure that forms of life-threatening agency were 'cancelled out' (a distance that is theoretically demarcated by the extreme limit of the outer zone), the use of these calculative practices enables a negotiation of interests to take place, and permits certain developments to occur within specific areas. A more definite line of unacceptability can be seen to be in operation, however (as is indicated by the boundary of the zone of highest risk). Past this, all development is prevented. Relational partitioning thus operates through a bandwidth of action that distinguishes an ideal, but negotiable, relational distance and a line of absolutely unacceptable proximity.

The second practice of relational organisation then involves: _2) the construction of 'blocking relations'_. For gas to realise its explosive agency, it needs to form relations with oxygen and a source of ignition. To do this it must somehow come to circulate beyond the pipe (or oxygen and heat must find some way of entering the NTS). For either of these events to happen, the external relationship that the gas possesses with the pipe must change; the integrity of the pipe walls needs to be compromised. As such, the walls of the pipe can be understood to form a kind of relational block around the gas. Through the gas's formation of relations of exteriority with the pipe walls, certain other exterior relations come to be cordoned off – as one set of relations becomes actualised, so others become relegated to virtuality. A relational partition is thus formed through the totalising presence of these particular material elements that saturate the actuality of the gas, excluding the actualisation of other virtuals. In this way, the latent agency of gas (in this case, its ability to cause loss of life through an explosion or jet fire) again becomes inhibited through the creation of a partition, albeit one that is formed through the creation of blocking relations, not through the production of spatial distance.

These kinds of relations require a considerable amount of effort, however. The transmission pipes in this example have to be made to exacting specifications. Their constitutive materials must possess certain strengths and levels of fracture toughness (a measure of their ability to resist fracture), and their wall thicknesses and diameters are carefully regulated, dependent upon the pressure of the gas flowing in that section of the network, and dependent upon the presence of perceived external threats (such as vibrations from nearby traffic). Every pipe also has to be checked and tested for minute imperfections and weaknesses, prior to normal operation[167]. In this way, different pipes are designed to more-or-less reliably block gas from forming certain kinds of external relations, dependent upon the particular properties and pressures that the gas possesses[168], and the kinds of external threat that are perceived to be present within that pipe's milieu.

Again, just as relational distancing practices should not be understood as a means of absolutely eradicating relational phenomena, blocking relations should never be understood as fixed and permanent. They are precariously performed, and their forcing of other relations into virtuality is consequently always subject to resistance, is only ever temporary, and is not guaranteed.

This can be clearly seen in the example of the resistance presented by corrosion. As Muhlbauer (2004; 61) explains, 'manufactured metals have a

[167] Industry standards (IGEM, 1995).
[168] Every pipe is allocated a maximum operating pressure.

natural tendency to revert to their original mineral form' (a process known as corrosion). To differing degrees, corrosion affects practically all of the metal pipes in the NTS. It also presents considerable risks for the transportation of natural gas, because any reduction in pipe wall thickness can threaten the structural integrity of these pipes and therefore increase their risk of failure (Ibid). Such risks are made more significant by the high pressures and volumes in which gas flows through the NTS, for it puts a high level of stress upon the pipes and creates the potential for larger scale incidents. Corrosion therefore constitutes a resistive force to the work of the pipe's blocking relations. Far from the pipe forming a permanent and guaranteed partition between gas and other external actants, its performances of security are always subject to resistive forces that work to undermine it. Without additional practices (such as the application of anti-corrosion measures), these relations will eventually break down, enabling gas to realise other forms of external relation. Security therefore has to be continually performed.

For the transmission pipe in figure 17, corrosion takes two forms; internal corrosion, whereby the pipe corrodes from the inside out (usually due to a reaction between the pipe walls and the transported product), and subsurface corrosion, whereby the pipe corrodes from the outside-in (primarily due to either a chemical reaction between the pipe and the surrounding soil, or because of the presence of stray electrical currents). Industrial responses to internal corrosion can be seen to present a third practice of relational organisation. This takes the form of: *3) the manipulation of gas's relations of interiority*. The primary means of addressing internal corrosion involves a chemical alteration of the corrosiveness of gas. Natural gas's principle acidic component is hydrogen sulphide, which is present in raw natural gas in varying volumes, depending upon the characteristics of the well from which the gas is extracted (Interview, Shell Operations Manager, 2nd April 2015). Hydrogen sulphide reacts with water molecules that are present within the gas (or which have found their way into the inside of pipes via other means), and this reaction results in the formation of hydrosulphuric acid, a substance that can eat away at the steel pipe walls (Amosa, Mohammed and Yaro, 2010). Both hydrogen sulphide and water molecules are consequently removed from natural gas through the use of sophranol and silica bead filters, prior to it entering the NTS[169]. In this way, natural gas's relations of interiority are directly manipulated, with threatening constituents being isolated and their agency being neutralised as the gas passes through the processing terminal. A line is thus again drawn through gas's relational cosmos, with unacceptable relational forms being isolated in order to strategically inhibit the agency of the circulating gas. This process of inhibition is distinctly different from the techniques described previously however, for the changing of gas's relations of interiority means that its inherent capacities and the constellation of virtualised relations that surround it are also directly altered. As such, the manners in which gas can interact with its proximate neighbours undergoes a radical transformation.

In addition to the management of internal corrosion through the alteration of gas's relations of interiority, efforts are also undertaken to manage the forms of corrosion that take place upon the outside of pipes. In these efforts, a fourth practice of relational organisation is visible. This practice involves: *4) the reinforcement of security apparatuses with successive layers of additional relations.* Subsurface corrosion generally occurs if four requirements are satisfied[170]. An anode must be present; a cathode must be present; an electrical current must exist between them; and an electrolyte must be available to conduct this current. Anodes and cathodes are defined through their affinities for electrons (a property that is known as electronegativity). Different areas in pipe surfaces will naturally possess higher or lower levels of

[169] Interview, Operations Supervisor, St Fergus Gas Processing Terminal (2015).
[170] Data taken from Muhlbauer (2004).

electronegativity, and areas that have higher electronegativity are referred to as cathodes, whilst lower areas are referred to as anodes. The greater the difference in electronegativity between cathodic areas and anodic areas, the more likely electrons will flow between them. This electron flow requires a conductive electrolyte however, which is typically provided by the soil. Should each of these requirements become actualised, an electrical circuit will form, causing metal from the anode to dissolve and migrate to the cathode, leaving inconsistencies in the surface of the pipe. If unchecked, these inconsistencies can create severe structural weaknesses in the pipe walls, and can increase the likelihood of their failure.

To govern this process of external corrosion, anti-subsurface corrosion systems are employed to prevent these kinds of relations from forming (Muhlbauer, 2004). There are two main techniques that are employed for this purpose. The first involves coating pipes with insulating materials that isolate the pipe from the surrounding soil. This forms an additional kind of blocking relation on top of those formed by the pipe walls, whereby the coating interrupts the formation of the corrosive electrical circuit, theoretically halting the decay of pipes. As such, we can observe the formation of successive layers of blocking relations around the gas, these layers working to reinforce the performance of security that is conducted by the pipe. Not only does the pipe wall block and exclude other external entities from forming relations with the gas, but this action is backed up by the work of an additional layer of blocking relations (the coating) that blocks the pipe walls from forming relations with the electrolyte. In this way, an attempt is made to force successive layers of virtuals to retain their virtuality, effectively 'cancelling out' escape-related phenomena.

As always however, resistive forces continue to operate. Inconsistencies in coatings (which may be microscopic) are impossible to eradicate, and corrosion can consequently continue to occur (Muhlbauer, 2004). To compensate for this, attempts are also made to form further relations around the gas. In this instance, this involves the burying of 'sacrificial' anodes (bodies of metal that have a markedly lower electronegativity than the materials the pipeline is made of) alongside pipelines. These anodes work as substitutes for the pipe's anodic sections, causing an electrical relationship to preferentially form between them and the pipe's cathodes. As a result, instead of metal migrating from one part of the pipe to another, it only migrates from the new anode to the areas of high electronegativity on the pipe. This results in the pipe actually *gaining* thickness and losing none of its structural integrity (Ibid).

Latour (1991) offers some useful concepts for coming to terms with the relational mechanics of this process of reinforcement. He suggests that certain imperatives (for instance, the assurance of public safety) can become reinforced and made more durable through the strategic creation of particular kinds of relational arrangement. These structures are described as 'programs'; meticulously constructed systems of relations that, through the careful arrangement of network forces, more-or-less consistently result in the production of particular given outputs (in this example, the inhibiting of gas's potentially lethal capacities). Through this process, imperatives become translated into logics, a logic being "a programmatic way of formalising, justifying and deploying actions in the here and now" (Anderson, 2010a; 779).

Latour is quick to point out however that such programmed systems of relations are always confronted with 'anti-programs'; different forms of resistive force that oppose the imperative put forward by the program. From this perspective, corrosion can be seen to be an anti-program, or resistive force, that opposes a larger ontological project of gaseous security. Like all anti-programs, it resists specific sets of relations – in this case, the blocking relations established by the pipe walls. In this way, corrosion exposes the pipe to also be mutable, eventually transforming it to a point where it ceases to have the necessary force to securely contain the gas. To counter these resistive forces and make the program more durable, Latour suggests that programs may be loaded with additional reinforcing relations (what he calls 'anti-anti-programs')[171]. The pipe coatings and the sacrificial anodes constitute a series of these 'backup' relations that work to counter the force of corrosion. As such, resistive forces are confronted through the creation of a forceful relational architecture that attempts to ensure that circulating elements comply with its imperatives. In doing so, reality is added to the imperative (Latour, 1991), and the ontologically 'secure' element comes to be actualised.

This is not to say that reinforced programs no longer experience resistance however. Whilst programs of relations can produce specific kinds of realities that are more or less durable, they are still never permanent, and are highly contingent and continuously performed (Law, 2007). We should therefore take caution in using Latour's notion of the 'immutable mobile' (a relational formation that retains its shape even as it moves across time and space). Indeed, rather than certain phenomenal objects being inherently immutable, we must take care to hold on to the notion that their forms and agencies are sustained through the governance of their actualised and non-actualised relations. As such, whilst some elements may indeed appear to be more durable than others, we must always remember that they are susceptible to politically significant transformations and failures. Such is the case with pipes and corrosion. Whilst anti-anti-programs may have been formed around the gas in figure 17, these corrosive forces can never be completely 'cancelled out' – they can only be 'compensated for'. Steel transmission pipes are perpetually

[171] There is a similarity here with Pickering's (1995) suggestion that these relational structures are developed through *practice* – that they are iterated upon to more successfully produce particular outcomes. Indeed, I suggest that incident reports and alterations to industry standards are clear examples of this iterative process.

vulnerable to degradation, and as a consequence, they will always be at risk of decay and failure.

A fifth kind of organisational practice can be seen to be closely associated with the recognition of this vulnerability to failure. This involves: *5) the formation of 'indicative', or 'surveillant', relations*. The vulnerability of security programs to failure is a consequence of the mutation of their relational architectures, but many of these mutating relations can be difficult to perceive through human senses. In the case of corrosion discussed here, such changes are largely insensible due to their occurring beneath the earth's surface. The perception of these relations may also be difficult for other reasons, too – including: relationships not presenting themselves within human affective registers; relations being widely dispersed across geographical space; or elements' relational movements being either too fast or slow for human observation. Because of these transformations however, and because of how they can lead to the emergence of particular undesired realities, attempts are frequently made to construct relational entanglements that provide indicators of change within programs. These indicative relations are engineered to reflect traces of gas's current relational arrangements in humanly perceivable ways in order that: a) the status of security programs can be assessed; b) advanced warning of the potential emergence of unacceptable phenomena can be facilitated; and c) the arrangement of new forms of securing relationship can be enabled. Various strategies are thus employed to collect traces of gas's relations and to thereby assess and monitor the status of programmed performances of security, in order that particular emergent scenarios can be avoided.

In the case of corrosion, indicative relations can be seen in the cathodic protection monitoring points that are placed across the transmission network, and also in the use of inline inspection devices, or 'PIGs'. Cathodic protection monitoring points are locations where a meter is installed to measure the strength of the electrical currents that are travelling across pipes[172]. Through these measurements, estimations of the voracity of corrosion on that section of pipe may be produced. Pipeline inspection devices, in contrast, operate within the gas stream. They are large, articulated, devices that are inserted into pipes and which travel within the gas flow, transmitting electromagnetic waves through the pipe walls and recording the signals that are bounced back. In this way, they enable the thickness of the pipe walls to be assessed and any irregularities (such as corrosion, cracks, dents) to be identified. These features are then mapped and evaluated to determine the necessity of repairs, prior to their failure[173]. As such, particular sets of relations are constructed around the gas to provide indicators of the efficacy of security's present performances, and to assess the forms of possible phenomena that may potentially become available to the gas in the future. In this example, it is the condition of gas's relations of exteriority that are being assessed. In other cases, however, such as in the use of chromatography units described in chapter 5, indicative relations will be employed to assess and monitor gas's relations of interiority.

In this way, indicative relations work as a form of relational 'trigger' that, if presented with particular stimuli, set in motion processes of relational reassembly. For instance, should a significant feature be identified during a PIG inspection, or should a cathodic protection point indicate an area of sustained elevated electrochemical activity, then teams of engineers will be dispatched to excavate and repair the pipes in question[174]. In this way, indicative relations work to render the security program actionable, and to enable gas's governing actors to reinforce this program with successive sets of additional anti-anti-programs so that the imperative of security retains its actuality.

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[172] Interview, former Network Director, Northern Gas Networks (2015).
[173] Site visit, PII Pipeline Solutions (2014).
[174] Interview, Emergency Operations Manager, National Grid (2015).

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From this analysis, I have identified 5 practices through which gas's constitutive relations of interiority and exteriority are strategically manipulated to 'compensate for' and 'cancel out' particular forms of emergent phenomena. These five practices are: *relational distancing; relational blocking; the reassembly of relations of interiority; relational reinforcement; and the construction of indicative relations*. Through a single example, security therefore emerges as an ontological project that is enacted across time and space by a complex heterogeneous collection of distributed elements[175]. Particular relationally-configured realities are perceived to present certain kinds of threat, and these realities are therefore manipulated to 'cancel out' and inhibit the forms of agency available to the gas. As such gas's relations must not be seen as static, but are instead arranged and ordered over space and time. Gas must therefore be viewed as being a shape-shifter.

Rather than such relational change being seen as simply something that must be prevented or secured against, however – where change equals threat, threat must be stopped, and thus change must be prevented – we instead need to appreciate how mutation functions as an instrument of security governance. Mutation is both the harbinger of existential threats, and also the means of protection. *Mutation is the primary tool of security*; it is the instrument through which the constitution of circulating elements is strategically manipulated.

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[175] These practices may not be the only techniques of relational governance in existence however, and other undetected practices may still operate upon the natural gas in this pipe.

It would be easy at this point to assume that mutation simply constitutes a tool of restraint: a governing practice through which the emergence of particular forms of threatening agency is only ever inhibited. Yet in the security performance that surrounds the pipe in figure 17, we can also observe several instances in which its relational structure is manipulated in order to *enable, or facilitate,* certain forms of gaseous action. Perhaps the clearest example of this can be seen in the way that compressors are used across the NTS. These compressors are employed to force gas's molecules closer together, increasing its pressure. This constitutes a manipulation of gas's relations of interiority that makes available to it new ways of acting. First, it provides the gas with a form of mobile agency: it provides the necessary motive force to enable gas to move within the NTS and distribution networks. Indeed, without this pressure, gas would simply stop circulating. As such, compression is a means of maintaining gas's circulation and thereby ensuring the security of supply. Yet it also assists this objective in a second way – by providing gas with the ability to meet the immediate demands that are placed upon the gas transport system. It enables large volumes of gas to be contained within the NTS at any one point in time, and thereby ensures that sufficient gas is available to meet consumer demand[176]. Moreover, it also provides gas with the ability to assist with dealing with unexpected demands that are placed upon the system. It provides a mechanism for storing an excess of gas within NTS pipes, and this process, known as 'line packing', enables network operators to maintain supply during periods of high demand. As the emergency operations manager for National Grid explained;

"You know, we do get notifications to say what is happening. We should have an hour or two, or more, to be aware of a big change that is about to happen on the grid…so, erm, we use the line pack, to you know, pre-empt it." (Interview, Emergency Operations Manager, National Grid, 2014)

[176] The closer molecules are together, the more gas can be contained within a given space.

Yet whilst gas's relations are manipulated to promote the realisation of these specific forms of agency, such alterations also endow the gas with other – less desirable – capacities. Increasing the pressure of the gas via 'line packing' not only enhances its motive force, but also increases its resistance against the blocking relations that are established by the pipe walls. When combined with the greater volumes that it enables the gas to travel in, the gas can be seen to develop the capacities to produce larger escape events such as jet fires and vapour cloud explosions. Relational organisation practices are thus not simply inhibitive; they must also be appreciated for their simultaneous productivity – not all forms of which might be desirable.

Indeed, every kind of relational restructuring both facilitates and precludes certain forms of actual and potential agency. The blocking relations of the pipe walls, the shifts in interior relations, the distancing of certain external actants and the leaving in place of others, all simultaneously inhibit particular ways of acting, but also bring new forms of gaseous agency into existence. Indeed, without these relations, gas might not warm houses, heat food, or turn turbines.

All relational arrangements also remain open to the possibility of resistance and opposition, regardless of how durable or oppressive they appear to be. As such, it is futile to characterise certain configurations as inherently restrictive, or oppressive, and others as being fundamentally enabling, or liberating. Instead, we must pay close attention to what forms of agency come to be promoted and inhibited through these security performances, what the effects of particular actions upon other actants are, and what the logics are that drive these performances[177].

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[177] Indeed, this interplay between liberating and oppressive relational arrangements is something that Foucault was intensely aware of (see Foucault and Miskowiec, 1986).

Indeed, such logics may be manifold. Within the practice of compression for example, two logics are particularly visible. First, we can observe a concern for safety, whereby the performance of security is structured around the imperative of avoiding injury to human bodies. This is the logic that (amongst others), drives the formation of the blocking relations that constrain the gas; the practices of relational distancing that prevent houses from being built near pipelines; and the use of corrosion monitoring practices through which attempts are made to avoid a breakdown in the integrity of security performances. Second, we can observe a logic that concerns the security of supply. Here, the performance of security has been structured around the imperative of maintaining the circulation of gas relative to consumer demand. This is also the logic that, amongst other actions, drives the gas's pressurisation[178].

The emergence of multiple logics and their influence upon security programs can, I suggest, be understood through the distribution of agency across these programs. As has been implicitly stated thus far, performances of security are not conducted according to the discretion of a single, centralised actant. Instead, each actant (HSE, National Grid, gas, the pipes, the ground workers that threaten them, local property developers, and so on) has its own agendas and imperatives, and these become subject to ongoing processes of negotiation. Depending upon the way that force is distributed across these relations, certain agendas or imperatives will come to be more or less influential in defining the characteristics of the security program that is formed around gas's circulations at any one point in space and time. Those imperatives that succeed in influencing the way in which gas's reality is constituted (to a

[178] A number of other logics, including ones focused around concerns for cost, ethics and environmental conservation, may also be operating in the program of security that has formed around the gas in this pipe.

greater or lesser extent), become converted into security logics that drive, or structure, the way that security is programmed/performed.

The emergence of potentially heterogeneous logics leads to a programming of security that, whilst sometimes complementary, can also contain inherent tensions. This is because pursuing a single logic to its extreme conclusion may necessarily entail the making of concessions regarding the fulfilment of others. To completely ensure individual safety for example, it might be necessary to transport gas at insufficient pressure to meet demand, or to completely cease the transport of gas altogether. Instead of single logics becoming totalising, a shuffling of imperatives therefore has to arise through which gas's relations come to be organised according to different negotiated logics.

We can see the results of such negotiations in the case of gas's compression. Supply and safety logics coexist in tension, and in order to respond to the increased threats that the pressurised gas poses, a compromise has to be developed through an act of relational compensation. Whilst gas's pressure is raised to maintain supply, adjustments are simultaneously made to the arrangement of gas's relations of exteriority in order to bring the risk of hazardous phenomena actualising down to an acceptable level. In this instance, this results in pipes being thickened and shielded with concrete slabs, and in their being distanced from human settlements through the application of land use planning strategies[179]. As such, we can observe a process of relational jostling and programmatic rearrangement taking place, through which particular forms of gaseous agency are facilitated, and others are inhibited, dependent upon the outcome of the ongoing negotiations of interests between governing actants.

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[179] Interview, former Network Director, Northern Gas Networks (2015) and industry standards (IGEM, 1995).

I want to suggest that such processes of negotiation and the emergence of heterogeneous security logics is particularly valuable for a security literature that has been principally concerned with performances of security in relation to singular referent objects, and that has typically imagined security as being programmed in a more-or-less coherent way around individual concerns (such as the protection of the nation-state, or the protection of global climate). In contrast, this approach invites security scholars to appreciate the multiplicity of referent objects and associated interests that filter in to security performances, and to come to terms with the way that these interests come to be negotiated. The tensions and synergies between competing agendas, their negotiations, and the political consequences of these arrangements, requires much greater critical attention.

IV. Securing Natural Gas (II): Longitude

What I have presented so far has been a kind of 'snapshot analysis'; a vertical slice through the pipe that has involved the tracing of a complex set of relations that converge upon a singular point in time and space. In isolating my analysis to this single point however, it is easy to assume that performances of security involve attempts to organise gas's reality in such a way that it becomes relatively fixed; that gas is rendered secure once and for all through the formalisation of a single acceptable configuration of actualised relations that is maintained throughout the entirety of its circulatory journeys. This, I contend, is far from the case. To demonstrate this, I now turn to an alternative example: a distribution pipe in a residential street in Middlesbrough (figure 18). In taking this example, and by undertaking an additional successive lateral slice through gas's relations at this point in its journey, I suggest that we can begin to develop a longitudinal appreciation for the way that gas's interior and exterior relations come to be organised differently along the length and breadth of the UK's gas transport infrastructures.

The gas in figure 18 is travelling through a recently installed section of polyethylene pipe that is located in a residential street in Middlesbrough. This pipe is distinctly different to the one in figure 17, for whereas in the previous example, we were dealing with gas's circulation at high pressure, this new pipe is part of a distribution network, and through which gas travels at low pressure. In holding two 'slices' of performances of gaseous security in relief with one another in this way, I hope to vividly showcase the contrasting differences in how gas's relations are (re)configured at different points in space and time by differently programmed security performances.

Figure 18 - Photograph of a distribution pipe in Middlesbrough, 2015

In selecting pipes from two apparently discrete networks however, there is a danger that a Foucauldian disciplinary logic could be read into these examples – a logic through which gas could be seen to circulate through a number of discrete and enclosed disciplinary environments. Such an approach would consider each of these enclosures to possess distinct and rigid sets of formalised practices of security that are consistently conducted in the same, programmed, ways throughout their territories of influence. This is not my intention. Such a reading would overlook the intricacy of security's performance, and would ignore the manifold and constantly changing ways in which gas comes to be ontologically arranged. Far from describing 'segmented', 'immobile', or 'frozen' sets of relations, where relational configurations come to be "fixed in […] place" (Foucault, 1977; 195), I highlight the transience and mutability of gas's relations during its travels.

Indeed, I consider Deleuze's (1992) notion of modulation to be a more appropriate concept for describing gas's governance. According to this approach, we can view security as being performed around gas through the exertions of a series of 'self-deforming', or 'modulating', assemblages that are strategically designed and enacted by a collection of elements (p.2). Unlike the prison, the hospital, or the asylum – architectures that constitute "explicit programs; […] sets of calculated, reasoned prescriptions in terms of which institutions are meant to be recognised, spaces arranged, [and] behaviours regulated" (Foucault, 1991; 80), and even unlike the programs that are described by Latour (1991) and Law (1986), where elements are rendered durable within space and time through enduring configurations of social relations, these modular programs conform to no such fixity. They are constantly in the process of (re)assembly, and security is consequently performed differently across the entire extent of gas's circulatory journeys.

Whilst the notion of modulation has valuable utility for visualising these shifting performances of security however, my operationalisation of it differs significantly from Deleuze's. This is because Deleuze, like Foucault, insufficiently attends to the specificities of the relational transformations that are undertaken by the materials and bodies in circulation. In this section, I draw attention to the way that modulation involves a series of meticulous relational reconfigurations that edit the agential qualities of the elements being governed. Gas's governing assemblages, I argue, "transmute from point to point" (Ibid; 4), organising gas's configurations of actual and virtual relations as they orbit around it, and thereby causing it to ontologically mutate. As such, modulation is a practice of governance that orders the realities of entities in the attempt to inhibit or facilitate the emergence of particular relational phenomena; it is a means of securitising mutation. In order to understand this process however, we have to explicitly attend to the material qualities of the 'thing' in motion, and identify what qualities and forms of agency actors seek to 'cancel out'. In the section that follows, I therefore examine how, at the scale of gas's relations of interiority and exteriority, multiple programs of security come together to organise and compensate for gas's relations in different ways across space and time.

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The most immediately obvious difference between how security is performed around the gas in the Middlesbrough example and how it was performed around the pipe in Norfolk, regards the propinquity of people and buildings. Within distribution networks, not only is it fundamentally necessary for the gas to approach homes and businesses (for homes and businesses form the sites of consumption), but it is also simply not possible for governing actors to structure and arrange urban fabrics in the same way as they manage the milieus of transmission pipes. There is an obstinacy and durability to the urban landscape that often resists extensive manipulation (Karrholm, 2007), and this landscape is home to an array of interests that seek to organise it according to a variety of different, often competing, imperatives. As such, the ways in which gas's relations of exteriority can be managed within these built environments is subject to considerable constraints.

The durability of the built environment and the rhizomatic nature of the distribution network also contribute two further limitations to these gaseous security performances. First, they result in the maintenance of pipes being extremely costly and difficult, particularly when these pipes run under existing developments such as roads, railways and buildings. Partly for this reason, many of the pipes in operation in distribution systems in the UK are legacy pipes from earlier town gas networks. Some of these pipes may now be very old and in need of repair[180].

Secondly, the rhizomatic nature of these pipelines means that the in-line surveillance techniques that are employed to assess asset health within the NTS cannot be used. Because PIGs need to have a definite point of retrieval and can become stuck in locations where pipes diverge, they can only be used within linear pipeline systems[181]. As a result, it is often very difficult to directly assess the severity of corrosion in distribution pipelines across a large geographical area. Many of these pipes are therefore ageing and possess uncertain integrity. As such, they may be unable to perform the necessary blocking relations that are required to inhibit the gas from actualising threatening kinds of external relation. As such, whilst leaks on the transmission system are very rare (indeed, any leak could be catastrophic due to the high

[180] Interview, Health, Safety and Environment Manager, Northern Gas Networks (2014).
[181] Site visit, PII Pipeline Solutions (2014).

pressures at which gas is transported within this network), such leaks are relatively common within distribution networks[182].

For these reasons, gas cannot be performed as a secure circulating entity in the same way that it was within the NTS. As such, the program in figure 18 looks quite different to the one in figure 17, involving a series of different organisational actions that are undertaken upon gas's relations, these actions causing the gas to mutate into significantly different forms that provide it with very different kinds of material agency.

A major difference in the security program that surrounds the Middlesbrough pipe for example, concerns the way that gas's relations of interiority are structured. As with the gas in the NTS, gas's pressure within distribution systems is strategically manipulated. Whilst the NTS typically raises the pressure of gas to as high a point as possible to provide motive force and a form of storage, the pressure of gas within distribution networks is reduced to as low a point as possible, in order to minimise the rates with which gas leaks whilst still maintaining its circulation[183].

This alternative programming of gas's reality is driven by a shift in governing logics. The logic of safety is most influential here, for significant volumes of escaping gas have the potential to result in fire and explosion risks (particularly if they accumulate in spaces such as drains, ducts and buildings)[184]. These fires and explosions are also more likely to produce casualties or property damage, due to their proximity to residential areas.

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182 Interview, Emergency Operations Manager, National Grid (2014).
183 The higher the pressure in relation to an external atmosphere, the faster gas will escape from a compromised pipe. Interview, Health, Safety and Environment Manager, Northern Gas Networks (2014).
184 Site visit, 'Escape Chasing' – Northern Gas Networks (2015).

Security of supply also continues to play a role in these programs, but the rhizomatic geography of the distribution pipework now reduces the number of people that are dependent upon any single pipe, and as a result, supply is less of a concern than it was on the NTS. As such, safety comes to override the logic of supply in the Middlesbrough context, this imperative precluding the transport of gas at high pressure within these environments.

Such logics of safety and supply security do not exist totally in tension, however. Whilst high pressures are not permitted by the logic of safety, a minimum pressure of 35millibar must still be maintained as the gas enters properties. If this pressure were to fluctuate, the flames in domestic and industrial appliances could go out, potentially allowing the gas to subsequently enter these properties without being burnt. This could permit the gas to accumulate in potentially explosive volumes, and as such, whilst the logic of safety and the logic of supply maintenance can be seen to have shifted in relation to one another (dramatically altering the way that the security program is structured), this situation demonstrates how their interests can at times be complementary.

This is not to suggest that a rigid practice of pressure governance is consistently performed across the entire extent of distribution networks however. Pressures are not the same within all locations of these systems[185], for different pipes operate at different pressures, dependent upon the kinds of threats that the gas is perceived to present, given the different kinds of pipe through which they are travelling, and the various types of environmental feature in their proximity (such as buildings and infrastructures). Pressures will also vary depending upon the amount of motive force that is considered

[185] Site visit, Regional Control Room, Northern Gas Networks (2016).

necessary to transport the gas to the furthest extremities of the network, and to thereby ensure the 35 millibar minimum pressure[186].

In addition to gas's pressure, its internal relations are also altered in another way. At NTS off-take points (the sites at which gas is transferred from the NTS to regional distribution networks), the gas entering the distribution system has a humanly-perceivable artificial odorant added to it, the molecules of which mix with those of the gas to become inseparably entwined. This internal adjustment acts as an indicative relation. Whilst gas in the NTS is invisible, odourless, and intangible, in distribution systems where leaks are more prevalent, gas's relations of interiority are manipulated to render it physically sensible to humans so that it can be detected before it realises its explosive or flammable agency[187]. In distribution systems, the lowered pressures and smaller volumes at which gas circulates mean that unodorized gas would likely be insensible to humans. Combined with the prevalence of leaks that occur within these networks, and the proximate urban infrastructures that may provide enclosed spaces in which gas could accumulate, this can result in leaking gas amassing in sufficient atmospheric volumes to realise its explosive capacities without being noticed. In an attempt to address this potential phenomena, gas is thus odourised: its relations of interiority are manipulated in such a way that they form an indicative exterior relation with human bodies that triggers particular kinds of relational reassembly.

Odourising gas in this way marks a radical shift in the practice of security, compared to the way security was performed around the gas in figure 17.

[186] Site visit, 'Escape Chasing' – Northern Gas Networks (2015).

[187] Such alterations are not considered necessary within the NTS, due to how the pressures and volumes of gas would result in any leak to result in such a catastrophic incident that it would already be rendered sensible through the noise of its release, its visible effects (such as the propulsion of soil and debris, or a plume of flame), or through physical sensation (such as through the heat produced by its combustion, or through atmospheric force) Interview, Emergency Operations Manager, National Grid (2014).

Instead of isolating human bodies from physical contact with it, here the gas is intentionally made to press upon, and form sensory relationships with, people. Indeed, these relationships are extremely specific, and have been carefully engineered at a molecular level – the odorant being designed to encourage gas to form relationships with human bodies that have three specific qualities that relate to its detection, distinction and the manner in which it is responded to. Regarding detection, this odorant has been designed so that it is only humanly somatically perceptible when the gas achieves certain volumetric limits within an atmosphere. As an engineer involved in the development of a suitable odorant for Wales Gas (the company responsible for the Welsh distribution network in the 1980's), describes:

"Quantitatively, gas odour should clearly be sufficient to provide an adequate safety margin whilst not being high enough to cause an unnecessarily large number of district complaints" (Craggs, 1981; 1)

Gas's interior relations are thus arranged so that it only forms indicative relations once a leak reaches a particular severity. There are three reasons for this. First, the cost of individual excavations and repairs within distribution networks is high, due to the amount of disruption that they involve and the high costs of materials. Second, the prevalence of leaks means that the total repair of the distribution networks is an economically unfeasible endeavour; there are simply too many leaks for gas distribution companies to realistically fix. And third, many of these leaks are deemed to be unlikely to result in an explosive incident, due to the gas not being able to achieve a sufficient atmospheric ratio with the air to realise its explosive capacities. In order for natural gas to ignite, between 5% and 15% of a given atmosphere must consist of methane, and the remainder must consist of air[188]. Many of the leaks within distribution networks will either be so minor that they do not release enough

188 Interview, Resilience Manager, County Durham and Darlington Fire and Rescue Service (2014).

gas for it to achieve these explosive limits, or they will occur in locations that are distanced from inhabited or enclosed spaces in which it could accumulate, ignite, or cause injury. In these cases, the cost of the lost gas is typically considered to be less than the costs of repair, and the gas is therefore allowed to continue to safely dissipate into the atmosphere[189].

Because of these constraints to repairs, gas's odorant has been designed to form a particular kind of indicative relation that is based upon its explosive limits. Rather than indicate the presence of gas only when it achieves potentially explosive volumes, the odorant is designed to become perceptible significantly before the gas nears these limits. In this way, a safety margin is established; the gas forms a carefully crafted indicative relation that is designed to provoke a relational reassembly before the phenomena of a jet fire or explosion can become actualised, but at the same time enables the costs of repairs to be minimised. As such, we can see the negotiated interplay between two logics; one economic, and one of safety, and this negotiation results in a performance of security through which both interests are accounted for with varying degrees of efficiency.

The second quality of the gas/human relationship facilitated by this odour then regards its distinction. The odorant has been designed so that leaking gas is easily distinguishable from other environmental odours. As Craggs explains:

"Qualitatively, the odour should have 'impact' and be distinctive, that is, definitely 'gassy' and not like old cabbages or petrol. Also, it should not fade in intensity in the transmission system" (Craggs, 1981; 1-2)

As such, the gas's relations of interiority are specifically engineered so that, not only does it press upon human olfactory organs in a volumetrically specific

[189] Site visit, 'Escape Chasing' – Northern gas Networks (2015).

fashion, but it does so in such a way that enables an actionable response. In order for members of the public to identify gas leaks and be certain of their diagnoses, gas's odour must be unambiguously identifiable and must always retain the same characteristics – regardless of the age of the gas or the odorant. An ambiguous odour may increase the number of leaks that are erroneously reported, or it may lead to a decline in the reporting of actual leaks, due to the public mistaking the origin of these odours for some less hazardous source. Furthermore, a distinctive odour can increase the speed of response, enabling the public to rapidly identify leaks and potentially trigger the security programs' relational reassembly before the gas realises its explosive or flammable agency.

The third, and final, quality of gas's olfactory relationship with humans regards the forms of action that this odour facilitates. As Craggs describes in the extract that follows, gas in distribution systems is designed to elicit a particular type of public response.

"The odour should be unpleasant – we have no wish to encourage 'gas sniffing' as a national pastime" (Craggs, 1981; 1-2)

The odour of gas is thus designed to be sufficiently offensive to deter members of the public from enabling its free circulation for personal pleasure: an action that could increase the likelihood of an explosive incident. Indeed, creating an offensive odour has the additional advantage of also potentially encouraging members of the public to physically distance themselves from the source of the smell, further inhibiting gas's potential lethal agency.

The indicative relationships of exteriority that gas forms with human bodies can therefore be seen to be carefully engineered to assume three specific characteristics: its easy detectability, distinguishability, and 'actionability'.

Instead of a practice of relational distancing, as was the case with gas in the example of the NTS, security in the distribution system involves gas making direct contact with human bodies, but in such a way that it notifies these individuals of its presence *before* its more destructive latent capacities become actualised. In this way, gas is configured to trigger complex acts of relational reassembly that work to inhibit specific forms of gaseous agency reactively, as they emerge.

Furthermore, whilst all gas within the distribution system is odourised at its point of entry, we should again not see this practice as a feature of a disciplinary enclosure. This is because the detection of gas's odour at different points in its circulation does not necessarily elicit the same kinds of reactionary response. Should gas be detected within a property for example, and should it not be able to be shut off, then emergency responders will have to attend the scene within an hour[190]. In the case of the gas being able to be turned off however, responders are required to arrive at the property within two hours. These response times are then coupled with the legislative requirements that are established in the Gas Safety (Management) Regulations (1996), that make it imperative that engineers repair or make safe the leak within 12 hours of it being reported.

Yet these rules are not universally applied along the length of pipelines, either. In the case of gas being smelled within a field for example, engineers will be sent to investigate, but they may not be required to repair it immediately, if at all. Instead, distribution companies modulate their responses based upon computerised risk-profiling systems that assess the relational context of the gas at that particular point in space and time and thereby determine the necessity

[190] Interview, former Network Director, Northern Gas Networks, 2015.

of repairs[191]. Various kinds of internal and external relationship are considered by these systems, their algorithms combining such factors as; the distance of the leak from properties, roads, footpaths and railways; the pressure of the gas in that location; the ground surface type; and distance of the pipe from areas of open ground. Through these algorithms, leaks in different locations across distribution networks are categorised into different degrees of risk. The most severe of these scores (for example, a leak within 500mm of a property) will necessitate its immediate repair and the leak's constant supervision until this repair takes place. Other scores may facilitate deferred action however, whereby their respective leaks will be allocated a certain frequency with which they have to be reinspected (3-7 days). Re-inspection will involve the risks presented by these leaks being recalculated, and the necessity of their repair reassessed. In this way, risk is anticipated to change across time and as such, the way in which the program is configured is temporally as well as spatially sensitive. In winter months, the open ground between properties and a leak might freeze, trapping the gas beneath the surface and enabling it to travel underground into houses. Similarly, other landscape features may transform over time, with new developments taking place, or temporary events occurring in leak locations[192]. As such, the relational milieus of all reported leaks is monitored, but the security response to these leaks will be different at different points in space and time – security is not performed through a disciplining enclosure, but instead, gas's circulation is secured through a modular performance that involves the formation of differently configured security programs around it at different locations, and at different times.

In addition to differences in the way that natural gas's relations of interiority are arranged, figure 18 also demonstrates the way that gas is arranged in terms of

[191] A print-out produced through these systems to categorize the risks presented by particular leaks can be seen in 'Image 9' in Appendix C.
[192] Site visit, 'Escape Chasing' – Northern Gas Networks (2015).

its external relations. Particularly interesting in this example is the alternative configuration of its blocking relations. Between 1971 and 1999, a series of high-profile explosions occurred within UK distribution networks. These were caused by the failure of certain kinds of pipe material (specifically cast and ductile iron) that were found to be particularly susceptible to fracture and corrosion. As a result of these explosions, the HSE insisted upon a nation-wide policy of distribution pipe replacement (HSE, 2001; Thomas, 2006). Under this program, distribution networks were required to replace all 'at risk' ductile and cast iron pipes with polyethylene pipes by the year 2030[193]. As such, the blocking relations that were formed by the old iron pipes are currently undergoing a transformation, becoming gradually replaced with ones made from more reliable polyethylene[194].

Despite polyethylene's material benefits however, mains replacement continues to be both costly and time-consuming. In order to minimise the risk of gas realising its flammable or explosive agency, but simultaneously reduce the costs of repairs, gas's exterior relations are manipulated according to an algorithmic risk analysis tool called the 'Mains Risk Prioritisation System' (MRPS)[195]. Through this system, all distribution pipes are allocated a risk score that takes into consideration the pipe materials, their age, their operating pressures, their diameters, their wall thicknesses, and their locational contexts. These risk scores are then used to prioritise the repair of particular pipes, based on the risks that they are perceived to present. In this way, the security

[193] Polyethylene was considered preferable because of its ability to form more durable blocking relations, it being far less brittle than cast iron, and not susceptible to corrosion.
[194] Interestingly, polyethylene pipes also have the additional benefits of their increased strength meaning that gas can be transported safely at higher pressures and in larger volumes through smaller pipes, and their enhanced flexibility meaning that it is often possible to conduct repairs despite the obstinacy of the built environment. Substantial excavation is often not required because new pipes can simply be threaded through existing iron pipes (as can be seen in the bottom of figure 18).
[195] Data for this example taken from Thomas (2006), and from 'Escape Chasing' site visits with Northern Gas Networks (2015).

programs that operate around gas are altered according to varying perceptions of risk. Any distribution pipes that are located more than 30 meters from roads or buildings receive a risk score of zero, meaning that they are perceived to present little to no risk to human life. This is because there is no atmospheric enclosure near enough to the pipe to trap the gas, and because these pipes typically operate at insufficient pressures to enable the gas within them to form vapour cloud explosions if it escapes – as such, any gas leaking from these pipes is expected to dissipate harmlessly into the atmosphere.

For distribution pipes that are located within 30 metres of property however, a range of risk scores may be allocated, dependent upon the configuration of a pipe's relations of interiority and exteriority[196]. Aspects of these configurations are assessed and combined to create three different risk factors that are then used to help constitute an overall risk score.

The first of these risk factors is referred to as the *mains fracture factor.* This takes into consideration the historic performance of pipes that share similar characteristics, and is used to assess the breakage history of all the pipes within 400metres of the pipe in question. The purpose of this measure is to incorporate an indicator of geographically specific corrosion or stress levels within the calculation. Through it, the current efficacy of the gas's blocking relations, as established by pipes of certain kinds, is assessed, and their need for reinforcement is estimated.

The second factor is the *gas ingress factor*. This is calculated by considering the diameter of the mains pipe (which affects the volume of gas likely to be released), as well as the distance between the pipe and the nearest property

[196] Data drawn from Thomas (2006).

(which indicates the estimated proximity required for the gas form lethal exterior relations with bodies). It also considers the area of permeable open ground between the gas and the nearest property (for leaking gas can travel through permeable ground and dissipate into the atmosphere, but concrete, tarmac, and even frozen soil can trap it and permit it to track under the surface into buildings), and whether the property has any cellars or basements. These could increase the explosion risk due to trapped gas being more likely to enter and accumulate in a below ground enclosed space, and because they are less frequently occupied by residents, the likelihood of a gas leak being detected is reduced. In these different ways, the potential mobile agency of gas is therefore assessed.

Finally, the gas *consequence factor* is calculated. This takes into consideration the typical operating pressure of the pipe (which affects gas's rate of accumulation), and the presence of windowless cellars. Windows are important for explosion risks, for they can enable ventilation and relieve atmospheric pressure. As pressurised gas accumulates within properties, the walls, ceilings, windows and doors that work to contain the gas become subject to outward atmospheric force, and these windows are often the first barriers to yield under the increasing pressure. Panes may shatter or be pushed out of frames, and failures such as these can significantly reduce the size and severity of an explosion – gas being able to escape the property and oxygen being able to enter, leading to the concentration of the gas falling below its explosive limit[197]. Because windowless cellars rarely contain sources of ventilation or pressure relief however, they can dramatically increase the size of explosions. As such, the consequence factor involves an assessment of the forms of potential destructive agency that could become available to the gas, should the blocking relations of the pipe break down.

[197] Site visit, RAF Spadeadam (2014).

In this way, we can see an act of relational 'compensation' taking place around circulations of natural gas. Through the application of the MRPS, gas's relations are manipulated according to the forms of agency that are perceived to be available to it. Gas that is believed to have the potential to form particular kinds of hazardous relations of exteriority due to its proximity to other elements, becomes subject to a systematic replacement of its existing blocking relations, with new, more forceful, relations being assembled to maintain the virtuality of these perceived threats. In contrast, gas that is considered to lack the proximate relations necessary for it to actualise such hazardous relations is instead allowed to continue to circulate, subject to the sets of blocking relations that have already been established.

The pipe in figure 18 exemplifies this situation well. Because this pipe runs under a tarmacked road that is less than 10 metres from two rows of terraced houses, and because there are no gardens or verges to provide any open ground between the road and these properties, the MRPS flagged it up as being in need of urgent repair. The original cast iron pipe that served these properties was consequently excavated, and was subsequently replaced with a new polyethylene pipe, as can be observed in figure 18[198].

This polyethylene pipe is still attached to part of the existing cast iron main however. As such, figure 18 provides an excellent illustration of the geographical extents of different programs of security – the joint that links these two pipes materially expresses their limits. On one side of the joint is the new polyethylene pipe. Because the gas within this pipe is considered to be within sufficient distance of people and properties to fulfil its latent lethal capacities, it has become the focus of a security program that involves the

[198] Site visit, 'Escape Chasing' - Northern Gas Networks (2015).

assembly of new blocking relations. On the other side however, a previously configured program of security remains in place. The ongoing work done by the cast iron pipe was not reinforced because the latent lethal agency of the gas within it was considered unlikely to actualise, due to the kinds of external entity currently available to it (this pipe was distanced further away from property).

Multiple logics can again be seen to drive the formulation of these two security programs – indeed, the MRPS was explicitly developed as a means of negotiating the tensions between the distribution companies' interests for financial security, and the interests of public safety that were expressed by both the government and these companies (Thomas 2006). Within this equation, logics of demand security therefore also became enmeshed in security's programming, as concerns were expressed for the continued consumer demand for gas if its price were to rise severely as a result of the cost of maintenance work, of if the public lost faith in the safety of the gas system as a result of further explosive incidents (HSE, 2001; Thomas, 2006). More recently, the logic of environmental protection has also begun to enter MRPS calculations, as system operators have become subject to government incentives and penalties in relation to the amount of methane they emit across their networks[199] (Interview, Northern Gas Networks, 21st October 2014). For distribution systems, where leaks are prevalent, mains replacement has become the primary means through which the environmental effects of methane emissions are addressed[200].

[199] Site visit, 'Escape Chasing' – Northern Gas Networks (2015).

[200] The cost of these penalties and the benefits of such incentives rarely makes the cost of excavating and replacing leaking pipe worthwhile however. Consequently, environmental logics only infrequently influence the formation of security programs within distribution systems (Interview with Northern Gas Networks Manager, 2014).

It is thus possible to observe a series of ongoing negotiations between the different interests of the heterogeneous actors that become involved in gas's governance. These negotiated interests come to structure security's programming. Engineers, investors, members of the public, property owners, highway authorities, politicians, pipeline operators, pipe materials, electrical currents, different soil types, diggers, not to mention the gas itself, all come to express themselves at different points in space and time, and as a result, enter into ongoing processes of relational negotiation.

As a result, multiple security programs must be seen to be produced. These programs are constantly performed, negotiated products that are constructed through the relative weight of these different interests. Their moment-by-moment relational arrangements do not simply operate upon gas's 'real', or actualised, relations (in other words, "the stuff that's 'already' there" - Nealon, 2008; 104), but instead simultaneously "work[…] on potentials" (Ibid; 104). Gas's virtual and actual relations of interiority and exteriority are thus constantly manipulated/modulated, throughout the entire length of its journeys in ways that both inhibit and facilitate the emergence of different kinds of gaseous agency at any one moment in space and time.

V. Conclusion: Modular Performances of Security

In this chapter, I have explored the way that security is performed in relation to the circulation of natural gas within the UK's gas transport infrastructures. In the process, I have demonstrated the presence of multiple practices of relational rearrangement through which security is performed. Five practices have been identified in particular. The first regards practices of relational distancing, whereby gas's agency is strategically inhibited through the removal of proximate entities with which it could form relations of exteriority. The second then concerns the practice of creating relational blocks, whereby gas is prevented from forming additional relations of exteriority, due to the totalising presence of other exterior relations. The third relates to the practice of rearranging gas's relations of interiority, whereby the entity's irreducible properties and latent capacities undergo radical transformation. The fourth concerns practices of relational reinforcement, through which programs of action may become supported and made more durable. The fifth regards the formation of indicative relations, through which threats to performances of security are identified, and through which processes of relational reassembly may be triggered. In outlining these techniques, I have argued that security must be conceptualised as an ontological project through which the realities of circulating elements are strategically restructured. I have argued that it is through this restructuring that certain forms of agency and contingent phenomena may come to be facilitated, compensated for, or inhibited.

Within this account however, security has not been presented as a singular performance. Security, as I have described it, is differently practiced in different locations, at different times. Its performance is shaped by a variety of logics that shift in relative importance according to the forcefulness with which the different heterogeneous actants involved in its governance can express their interests, and as such, far from describing a single articulation of what constitutes gas as a fundamentally 'secure' entity, I have argued that its relational constitution is *modulated* within UK gas infrastructures throughout the entire spatial and temporal extents of its circulatory journeys, according to the interplay of a variety of different security logics. Gas, as it is transported through pipelines, I argue, can therefore be seen to constitute Deleuze's (1992) modulated 'serpent', *par excellence*.

Crucially however, focus in this chapter has been placed upon the relational construction of modulated elements. Emphasis has not been placed on the specific political implications of individual events, because the events that could potentially arise must be seen to change throughout the extent of an entity's circulatory journeys. Whilst these events may be extremely important, the purpose of this study has been to focus upon the mechanics of security's practice. It is this focus on mechanics that has led this chapter to expand Deleuze's (1992) conceptualisation of modulation, describing how governing assemblages must be seen to operate upon the relationally constituted realities of circulating entities in the attempt to manipulate and manage the kinds of phenomena that can come into being.

Importantly, these relational arrangements must be recognised as being simultaneously both oppressive and liberating. Through the arrangement of both gas's actual and virtual relations of interiority and exteriority, certain forms of agency and the potential futures that they may actualise can come to be strategically inhibited, whilst at the same time, other forms of agency (some of which may be unintended or undesirable) may be brought into actuality. As such, the securitisation of mutation through modulation is both a productive and restrictive practice, and one that involves constant (re)negotiation.

So how might this understanding of modular performances of security have utility for critical security studies and energy security literatures? There are two particular thoughts that I want to conclude with. First, I suggest that an entity-attentive modular approach encourages us to draw our attention away from nodal centres of security. Following the charge rallied by Amoore (2006; 2007), it challenges us to think about security performances beyond well-trodden spaces such as the airport, the terrestrial border, or the locations of an entity's production and consumption. Instead, it requires us to think about the ways in which security comes to be performed throughout entities' circulatory journeys. In particular, it advocates *an attention to the way that circulating entities* *transform over space, acknowledging the potential alterations they may undergo in terms of their appearance, their actual and potential agency, the ways in which they move, and the ways in which their mutations become entangled with concerns for security.*

The second benefit then regards how we conceptualize the practice of security. Modulation, as it is envisaged in this account, encourages us to think about security in a way that counters the dominant narratives of filtration and supply maintenance. Both the security studies and energy security literatures are filled with such discourses. In attending to the ways that elements mutate however, and by looking at the ways in which these mutations are facilitated and restricted, we are forced to think about security under different terms. Instead of simply seeing practices of filtration or maintenance, security becomes reframed *as a constantly shifting project of relational organization that is differently performed, dependent upon the specific qualities of the elements in circulation*. I have offered a number of conceptual tools though which we might interrogate the forms of actual and potential agency that are strategically inhibited and facilitated at different points in space and time, and by examining such practices, I suggest that we may not only develop a better understanding of the political significance of circulating elements and the ways that they are perceived to present particular kinds of threat and opportunity, but that we may also improve our understanding of the mechanics of security performances in relation to specific elements.

7

Conclusion

I. Security and the UK Circulation of Natural Gas

This thesis has provided a detailed empirical account of the way that security is performed in relation to the circulatory journeys of a troublesome energetic material: natural gas. Working with a broad range of service providers and practitioners from various industry organisations (which have included National Grid, Northern Gas Networks, the Institute for Gas Engineers and Managers (IGEM), Shell, DNV-GL, Sick Engineering, PII Pipeline Solutions, Durham Constabulary, Durham County Council, Durham and Darlington Fire and Rescue Service, and the North East Ambulance Service), I have traced gas's journeys through both the UK's National Transmission System (NTS) and the North of England's gas distribution network. In the process, I have described how a series of security performances are conducted around gas as it travels across the UK.

Whilst gas circulations have typically been discussed in relation to security only with regards to their possible interruption and impact upon national energy security, they have been shown in this thesis to become entangled with security concerns in a number of ways. From concerns for public safety to fears for its environmental effects, costliness, and continued future supply, gas can be seen to develop a variety of perceived 'dimensions of dangerousness' (Dillon, 1996; Dillon & Reid, 2001) as it travels. Through these dimensions, gas's circulation introduces a series of threats and opportunities to everyday social environments, and it is these perceived threats and opportunities, I have argued, that lead to the development of multiple complex security apparatuses around gas circulations. Through such apparatuses, attempts are then made to both visualize the kinds of gaseous phenomena that are possible in a given moment (see chapter 4), and to regulate the conditions of possibility that affect their emergence (see chapter 6).

In studying these practices, I have drawn attention to a proliferation of typically mundane security performances that permeate everyday social environments. Such practices are rarely regarded in terms of security: they possess little of the visual spectacle of contemporary practices of border security, and often lack the gravitas of geopolitical security rhetoric. Yet whilst they may never result in the realization of spectacular security moments (although some can scale up to such events), and whilst they often fade into the background of everyday existence, I have argued that we must appreciate these actions for their securitizing roles. I have demonstrated that within them we can observe numerous attempts to facilitate, "compensate[…] for, check[…], finally limit[…], and, in the final degree, cancel[…] out" (Foucault, 2007; 37) different kinds of gaseous phenomena, according to different perceptions of opportunity and risk. As such, these actions constitute particular kinds of security practices. From the distancing of gas pipelines from roads, residential properties, and other kinds of infrastructural development in order to reduce the likelihood of gas forming life-threating relations with human bodies, to the alteration of its chemical constitution in order to change the way that it interacts with human bodies, pipes and gas burner jets and thereby 'cancel out' particular kinds of risks, within and across the UK's transmission and distribution networks, a whole series of security practices are employed to regulate the circulation of natural gas. Each of these practices, I have argued, involve attempts to both visualize the forms of gaseous phenomena that could form, and regulate the conditions necessary for their emergence.

II. Methodological Contributions: An Entity-Attentive Approach

Key to this thesis has been an entity-attentive approach that emphasizes the importance of the ontological specificities of the entities in security's focus, as well as the ways in which these qualities can present a series of security challenges across entities' circulatory journeys. Building on Dillon's (1996) observations regarding security's literary framing, I have criticized a tendency of researchers to abstract security from the entities to which it is applied. As Dillon (1996) notes, by treating security as a noun that is attached to multiple referent object prefixes (*national* security, *energy* security, *human* security, etc.), the concept has often been treated as an independent, broadly generalizable, set of practices that can be relatively unproblematically transferred from one context to another. This, I have argued, has been combined with an overwhelming focus on the structures of security governance within particular nodes (such as airports, maritime ports, points of overland border crossing, or control rooms), at the exclusion of analyses of the specific qualities of the entities in motion, the ways in which they come to be perceived to present particular forms of danger across their journeys, and the manner in which these qualities necessitate highly specialized sets of practices to 'compensate for', 'limit' or 'cancel out' (Foucault, 2007) their threatening potentialities – both within nodes, and whilst they are travelling between them.

Indeed, it is as a result of such abstractions that I have suggested that, when security is discussed in relation to circulation, it has often been reduced to two sets of abstracted practices: circulatory filtration (whereby risky entities are identified and separated from safe ones), and practices of circulatory maintenance (whereby circulations are managed so that insecurities resulting from their interruption or delay can be avoided). These two approaches typically obfuscate the qualities of the entities in focus, such entities often appearing as passive and inert. They consequently often appear as immutable mobiles (Latour, 1986): they are subjected to security's sorting, sifting and mobilizing practices, but they avoid radical transformation in the process. This, I have demonstrated, has particularly been the case for mobile materials. Whilst a number of studies have examined the performance of particular kinds of human security subjects (see, for example, Salter, 2007; Adey, 2009; Vaughan-Williams, 2015), practically no attention has been paid to to the ontological transformations undergone by matter as security is performed around it, especially as it travels between governing nodes.

In response to these particular complaints, I have advocated a grounded approach to the study of security, in which empirical attention is paid to the specific qualities of the bodies, materials and things across the full extents of their circulatory journeys, and to the ways in which these qualities become the focus of security's practices. Indeed, these qualities, I insist, are critical to understanding security. Gas has been shown in this thesis to be a material with highly specific qualities that make performing security in relation to it a difficult task. Whilst not totally immune to human sensation, it is typically invisible, intangible, and odorless, the circumstances under which it naturally becomes present to human senses being so specific and forming so rarely that, without intervention, it is affectively incoherent: its humanly sensible affects are so spatio-temporally distributed that it is difficult for humans to know when it is present, where precisely it is, how it is travelling, in what volumes, and what forms of agency are available to it at any one moment in time. As such, its particular material qualities present a series of challenges for taking securing actions upon it.

Moreover, in addition to its sensory evasiveness, its vitality has also been shown to generate problems for security. Gas is an extremely energetic and vital material, and whilst these qualities are precisely those that make it a valuable commodity for heating homes and for generating electricity, they also give rise to some of its most violent capacities: its ability to ignite and to explode, and its ability to damage property and to take life. Added to this, it has been shown to be highly recalcitrant. It constantly resists the containers that hold it, and its density relative to air means that unless it is contained, it will rise into the atmosphere and will dissipate irretrievably. It is therefore a particularly 'wayward' material (Bridge, 2004), and requires complex sets of securing practices to be performed around it at all times, simply to render it present and consumable.

Such different troubling material qualities also cannot be viewed as being fixed. A major theme in this study has been how the ontological structures of circulating elements are never rigid or firmly held in place. Gas ontologically shifts and mutates throughout its circulatory journeys, and the challenges it presents for security consequently also transform in the process.

To understand such ontological qualities and the challenges they present for security however, circulating entities have to be scrutinized through a relational lens. This thesis has built upon Foucault's (2007; 37) work, security being presented as a kind of reality management, in which security's actors seek to carefully restructure entities' realities in ways that regulate the conditions of possibility relating to particular kinds of phenomena.

Such realities (and the phenomena that emerge) have been analyzed through an assemblage approach advocated by DeLanda (2006), in which they are regarded as products of the actualization of particular kinds of social relations -

relations between their internalized components (their relations of interiority), and their relations with other external elements (their relations of exteriority). Gas, as an entity, has thus been framed as a relationally-produced material, the form and agency of which is contingent on the arrangement of its interior and exterior relations at any one moment[201].

Through this lens, gas's relational arrangements can be seen to be productive of specific kinds of security challenges, but it is not unique in being relationally constituted, or in its capacity for these relations to transform and mutate. Certain bodies, materials and things may be more susceptible to dramatic transformations than others, but across this thesis, I have maintained that all circulating entities (living or not) are subject to changing relational compositions as they travel, the nature of which can potentially radically alter the kinds of phenomenal future that are associated with their circulation.

As such, security, I have argued, involves attempts to manage these relations. It involves visualizing the forms of association that it is possible for entities to realize at any one moment, and by envisaging these relations in different ways, attempts can then be made to trace out the phenomena that could emerge, and to carefully and precisely restructure entities' constitutive relations, *their realities*, in ways that enable particular kinds of future event to be avoided, or their impacts mitigated.

As such, the specific ontological constitutions of entities are central to security's practice. Security researchers must try to *hold both the apparatuses of security and the entities being secured in focus simultaneously*. We must try to analyze the ways in which the qualities of security's entities of concern come

[201] The distinction between relations of interiority and exteriority is largely artificial, but serves as a conceptual tool for better understanding the relational constitution of circulating elements. See chapter 4 for a more detailed exploration of this point.

to be seen to present specific kinds of threats and challenges; the ways that they necessitate specialized kinds of security practice; and the precise manner in which these practices are designed to facilitate, 'compensate for', 'limit', or 'cancel out' (Foucault, 2007) particular kinds of phenomena through the ontological alteration of their realities. Such an approach, I suggest, will enable us to far better understand the mechanics and politics of security than is currently possible with existing accounts of security that frame it as practices of circulatory filtration or circulatory maintenance.

Methodological Principles of an Entity-Attentive Approach

To pursue such an entity-attentive agenda for future security research, I have advocated three methodological principles. These principles, which were employed in this study, are:

1. To focus upon the circulating entities with regards to which security is practiced. To observe and document the connections these entities develop with others, and to describe the ways in which actors seek to visualize and organize these relations. By attending to entities in these ways, I suggest that we can better understand how particular forms of threatening phenomena emerge, and how security is performed in response.

2. To follow the journeys of circulating entities, tracing the ways that their ontological qualities and security's practice change across time and space. By attending to the spaces and scales of circulations in this way, security scholars can produce accounts that exceed the spatial restrictions presented by nodal analyses.

3. To avoid making presumptions about the actors, practices, referent objects and security logics that are involved in security's performance. In response to the criticism that the existing security literature has tended to make assumptions about the transferability of security practices between entities and sites of analysis, I have sought in this study to reject prior assumptions about the ways in which security is performed in relation to gas, and to instead observe how efforts were taken to facilitate, compensate for, and cancel out particular kinds of gaseous phenomena.

Conceptual Approach to Security

By following these three principles, by beginning with gas as my focus, and by resisting the urge to assume the actors, practices, referent objects and logics that become involved in the performances of security that surround it, I have developed an account of security that not only challenges notions of security as a practice of circulatory maintenance or filtration, but that diverges in a number of key ways from existing narratives of security.

Security in this account is not simply a practice of bordering, or of defining exceptional phenomena that must be prevented/cancelled out. Instead, it is similar to accounts of biopolitical security (c.f. Dillon and Lobo-Guerrero, 2008), in that it is also seen to involve productive acts. Throughout this thesis, the 'exceptional' has been reframed. Gas has been seen to be governed in and through its mundane ordinariness – it is constantly secured all of the time, and not only in exceptional circumstances. As such, the exception is shown to have a relatively loose hold on the practice of security. Security takes a more managerial form, and involves constant attempts to enhance the efficiency and productivity with which gas can be transported, at the same time as attempts are made to 'compensate for' or 'cancel out' particular kinds of perceived threatening phenomena.

Yet my description of security's performance in relation to gas is also quite unlike biopolitical security performances. Biopolitical accounts are principally concerned with the referent object of the population, but in this thesis I have rejected the temptation to take a single referent object as my focus of study. Instead, security's referent objects have been allowed to proliferate. I have described how performances of security involve a multiplicity of actions, conducted by a vast array of heterogeneous actors, and each of these actors takes action upon gas in accordance with their own agendas, which often relate to very different referent objects. Politicians have been seen to take action upon circulating gas according to their concerns for national sovereignty, relating to the geopolitical and economic turbulence in the global trade of energy, but they have also been shown to simultaneously take action upon gas according to concerns for the security of the British population – these actors seeking to cancel out, or compensate for, particular gaseous phenomena that present risks to public safety. In contrast, network operators have been seen to express little interest in threats to political sovereignty, but to take action upon gas according to their concerns for the productivity, and potentially survival, of their businesses. In a similar manner, homeowners took action upon gas according to their concerns for the protection of their property and for their personal safety.

This thesis therefore does not provide an account of a singular referent object. It is not a study of 'national security', 'border security', 'climate security', 'economic security', or even 'energy security'. It fits none of these categories neatly. Whilst concerns for each of these referent objects (and others) filter into the actions that are taken upon circulating gas at different times, it is the contention of this thesis that security cannot be reduced to any one object in isolation, nor can it be reduced to any one space and scale at which these different referent objects might be analyzed.

Analytical Frameworks

In addition to these observations, a number of analytical frameworks were developed within each of the thesis's empirical chapters (chapters 4, 5, and 6). These frameworks, I suggest, may have value for studying security performances in other contexts. While they were developed specifically in relation to the circulation of gas, and like the conceptualization of security outlined above, should not be abstracted wholesale and applied uncritically to other contexts (indeed, different entities may have entirely different qualities that necessitate different practices, and the observations outlined here are certainly not exhaustive), despite these caveats, I believe that they could provide insights into the kinds of security practice that can be brought into focus through an entity-attentive research methodology.

Framework (I): Security and Visualising Possibility Spaces

The first framework, outlined in chapter 4, concerns the visualization of entities' possible future associations. Here, I drew upon DeLanda's (2013) concept of the 'possibility space', describing how the ontological structures of circulating entities are broken down into their virtual and actual relations of interiority and exteriority in ways that enable the identification of possible future phenomena, and which permit the strategic intervention in their realities, prior to the actualization of certain kinds of opportunity and threat.

In particular, I made the distinction between two kinds of mapping process, summarized in table 1. These visualization practices (blueprints and snapshots), enable different forms of strategic intervention to be conducted into the relational constellations that constitute the realities of circulating entities.

Table 1: Blueprints and Snapshots

Type of Visualization	Methods of Production	Example Formalizations
Blueprints *"More-or-less durable visualizations of entities' known possible associations and the phenomena they can give reality to."*	Experiments Investigations Simulations Speculations	Scientific Papers Investigation Reports Legislation Standards
Snapshots *"Near-to-real time visualizations of entities' present relational configurations."*	Mechanical Sensors *(chromatography units, pressure sensors, flow meters, temperature sensors)* Biological Sensors *(e.g. human noses)*	Data aggregation through user interfaces on SCADA systems Sensor Displays *(portable gas detectors, pressure readings, flow rates)*

Blueprints are more-or-less stable 'maps' of gas's spaces of possibility. They are not always literal maps (they often consist of reports, legislation and standards), but through them a series of known possible associations an entity can develop can be visualized, as can the phenomena that these associations are understood to potentially give reality to. They thus constitute formalisations of existing entity-related knowledges, and are used as points of reference against which particular kinds of relational manipulation – different kinds of securing action – are considered and deployed.

The other kind of visualization practice is the production of relational snapshots. These are more-or-less up-to-date visualizations of an entities' current relational configurations. Such visualizations are typically produced through a series of sensors (mechanical or biological) that enable particular attributes of the entity and the way it is currently circulating to be identified. They are typically compared to blueprints of gas's known possible relations in order to identify the forms of phenomena that an entities' current relational arrangements could potentially lead to. In this way, security actors can anticipate the emergence of particular kinds of phenomena, and attempt to apprehend them, whilst they are in the midst of their emergent becoming.

In the case of gas, I also described how this involves the construction of complex reflective apparatuses that produce multiple snapshots of different aspects of gas's current ontological structure, and that reflect these visualizations back to centralised points of observation such as control rooms and mobile workstations. This apparatus is particularly necessary in the case of gas – a material that flows through a geographically sprawling subterranean infrastructure that is otherwise impossible for a single observer to view in its entirety. As such, I described how the construction of reflective apparatuses enables the country-wide circulation of natural gas to be rendered spatio-temporally coherent in a way that permits different forms of securing action to be taken upon it.

In this manner, I have developed a framework for interrogating the ways in which security actors seek to map out and visualize the fields of possibility that relate to particular kinds of circulation. With regards to gas and the energy security literature, these everyday practices of mapping opportunities and threats across an energy infrastructure present a stark departure from accounts of energy security that ignore the circulatory journeys of energy products and reduce the forms of risk associated with their circulation to matters of interrupted supply or demand. In contrast, this approach highlights the proliferation of risks that can emerge across such networks, and provides a toolkit for analyzing one aspect of the extensive mundane security work that is conducted in the day to day operations of these infrastructures. Indeed, it also highlights the considerable vitality and dynamism of such circulating energy products. Energy security scholars need to far better attend to how energetic materials resist across their journeys; how they develop new forms of agency and can come to present new kinds of opportunity and threat – whilst they are in motion. Indeed, it is only by attending to these qualities that I believe we can properly understand recent events such as the BP oil spill in the Gulf of Mexico, the fires and explosions caused by the runaway oil train in Lac-Mègantic, Canada, or the meltdown of the Fukushima nuclear reactor in Japan. As can be seen so clearly in these examples, energy products are – in different ways – energetic and vital, and this vitality is generative of a plethora of insecurities. It is thus strange, and problematic, that this vitality has been so starkly absent from the majority of energy security accounts to date.

Turning to the critical security literature, whilst such practices have been observed in this thesis only in relation to gas and are therefore likely possess manifold contextual particularities, I believe similar practices can be observed in relation to other kinds of circulating entity, albeit in ways that reflect their own specific ontological qualities. Indeed, scholars such as Amoore (2006) and Vaughan-Williams (2010) have described how contemporary practices of airport security similarly involve attempts to break down the relationally-produced identities of individual people in ways that enable the identification of particular kinds of possible risk. Vaughan-Williams (2010; 1075) in particular describes a very closely related set of practices that are employed by UK firm, Detica, in its NetReveal security system, in which:

"Historical behaviour is contrasted with current behaviour, and high-risk changes are identified to alert the system operative to a potential threat. A map of activities, such as financial transactions, web bookings, and travel histories, can be compiled using billions of records from different agencies in order to build up a dynamic profile of individuals or groups. The stated aim of the NetReveal software is to allow data to `drive' the analysis in order to render networks of activity more visible than they would otherwise be due to the sheer volume of data. Applying this system to border security means that ``groups of related identities can be identified, correlated with known threats, and intercepted at the border before the threat can enter the country'' (Detica, 2009, page 4)"

As such, just as in the case of gas, visualizations of passengers' current relations and behaviors are contrasted against previously established blueprint knowledges of these bodies – these differences between visualizations then being used to identify particular kinds of threat, prior to their actualization. As such, these studies indicate the potential value of expanding this framework to explore the visualization of the relations of other kinds of circulating entity.

My approach introduces three novelties to this work however. First, it draws attention to the ways in which *materials and things* become the focus of similar practices of visualization, and invites further research into how the possibility spaces of other materials and things (for instance, waste, food, consumer goods, chemicals, etc.) are visualized and assessed in terms of the risks that they pose. Second, it emphasizes the broader application of these practices in other spheres of everyday life. Moving beyond the airport, maritime, or land border, how do such practices come to be employed in the relatively mundane, day-to-day security performances that permeate - and form the basis of - everyday life? Third, it highlights the extension of blueprinting practices beyond computer databases and algorithms into normalized, mundane forms, such as industry standards, legislation and policy documents, each of which involve different methods of production, and each of which enable different kinds of securing action to be deployed. Each of these strands deserves further analytical attention by security scholars.

Framework (II): The Security/Circulation Nexus

The second framework I provide concerns the different qualities of circulations and the ways in which they are productive of particular kinds of opportunity and threat (see chapter 5). Here, I build upon Cresswell's (2010) account of the politics of mobility, identifying six aspects of circulation that become entangled with concerns for security across gas's journeys. Again, the observations outlined here are not intended to be universally applicable or exhaustive, but are intended to provide a series of indicative examples through which to appreciate the significance of the circulatory journeys of entities *between nodes* for security's practice.

Table 2: Circulatory Qualities

Circulatory Qualities	Description
Paths/Circuits	Linear vs. Rhizomatic Uniform vs. Varied Unidirectional vs. Multidirectional Circulatory Milieus Expanded Points of Origin/Arrival/Transformation
Volume	3D Movements *Through* Volumes Voluminous Circulations - Volume as Quantity - 3D Circulations

Materiality	Appearances Textures Mutability
Forces	Motive Forces Frictional Forces Forces That Circulations Exert Other Forces Exerted on Circulations
Velocity	Velocity of Movements over Cartesian Space Velocity of Movements over Relational Space
Rhythms	Polyrhythmia Synchrony Arrhythmia

In this way, I provide a series of lenses through which to highlight the necessity of expanding security's analysis beyond centralized nodes, and through which scholars might usefully engage with the significance of entities' circulatory qualities for contemporary performances of security. Again, this framework has a broad range of potential applications. First, it has value for the existing critical security literature; a field of study that has consistently ignored the circulatory journeys of entities due to its overwhelming focus upon nodal sites of security's practice. Rather than focus only on nodes, this approach encourages attention to the ways in which concerns may develop across the travels of different bodies, materials and things. It invites questions such as: how, for instance, do the volumes of cargo affect the way that security can be practiced in relation to it in maritime ports? How does the velocity of relational change affect the way in which security is performed around the transport of donated organs? Of medicines? Of contagions?

Second, this approach has again got value for a literature on energy security that has tended to ignore energy's circulatory journeys, and which has instead been preoccupied with national-scale nodes of energy production and consumption. Security's practices and forms of insecurity that occur at other scales, between these nodes, have received minimal attention. The framework advocated in chapter 5 invites energy security scholars to consider the ways in which the materialities, and circulatory qualities of different energy products, necessitate security practices to be conducted around these circulations, across their journeys. By attending to such circulations more closely, I suggest that the energy security literature stands to gain a far better handle on the significance of energy products' lively material qualities, and will be able to ask a series of important questions about the way that energy security becomes a source of concern and is practiced at other scales. Potential questions that need to be asked include: how are concerns for security 'baked into' the designs of circulatory infrastructures? What phenomena are attempts made to facilitate, compensate for, and cancel out, through the design of these infrastructures? How is action able to be taken upon circulations, whilst they are in motion? What different actors and interests become involved in the conduct of these actions? What phenomena do they seek to influence, and how do their different interests become a locus for tensions, synergies and negotiations? Indeed, it is only by attending to the spaces and scales of energy circulations themselves that I suggest we can we hope to answer such questions and that we can come to understand security's practice in relation to circulating energy products.

Finally, this framework offers an expansion on the mobilities literature from which it draws inspiration. This framework builds upon Cresswell's (2010) account of the politics of movement, which like the majority of the mobilities literature, is principally concerned with human movements. By adopting a materialist lens, I offer key developments on each of his 'six constituent parts of movement', tracing out the different forms of security politics that can emerge according to these different circulatory dimensions. To provide an example, like Cresswell, I describe how such movements progress through volumetric space, but I go beyond this to document the security politics that surrounds the ways in which these circulations can, themselves, be voluminous in different ways. I also draw attention to the ontological qualities of the things in motion; their capacities to mutate and transform (with different speeds); and their abilities to exert forces of different kinds. Such expansions offer a framework of analysis through which the existing mobilities literature can be supplemented with accounts of the politics that surround different kinds of material mobilities.

Framework (III): Interrogating Security's Interventions

The final framework offered in this thesis concerns the practices through which security apparatuses work to shift and mutate circulating elements on a relational level to facilitate, limit, compensate for, or cancel out particular kinds of phenomena. In chapter 6, I argued that security must be seen to consist of a project – or series of projects – of reality manipulation. Five different kinds of manipulative action were identified in particular: the distancing of gas's relations of exteriority, the formation of relational 'blocks', the alteration of relations of interiority, the assembly of relational reinforcements, and the development of indicative/surveillant relations (see Table 3). Through the application of these techniques, I demonstrated how gas's mutating material qualities are not just the source of challenges for security's practice, but are central to the way that security comes to be performed in relation to it. In order to regulate and manage the forms of gaseous phenomena that can actualize in the future, attempts are made in the present to actively mutate the ontological structure of gas – its relations of interiority and exteriority, and the qualities and agency that it consequently exhibits – in highly specific ways.

Table 3: Practices of Relational Manipulation

Security Practice	Description
Relational Distancing	Strategically distancing external entities from circulations in order to reduce the likelihood of them forming relations with one another.
Relational Blocking	Encouraging the formation of particular kinds of external relation in ways that block circulating entities from forming potentially threatening relations with other elements (e.g. pipes blocking gas from forming relations with oxygen).
Rearranging Relations of Interiority	Manipulating the constitutive relations of interiority of circulating elements in ways that radically alter the forms of agential capacity available to them (e.g. removing hydrogen sulfide from natural gas to reduce its corrosiveness and toxicity).
Relational Reinforcement	Reinforcing individual practices of relational manipulation described above with successive layers of relational alterations (e.g. blocking gas from forming relations with oxygen through installing steel pipes, but then further supporting these relations by covering the pipes in polythene to protect them from corrosion).
Formation of Indicative/Surveillant Relations	Encouraging particular kinds of relation to form with circulating entities, changes in which provide an indication of potentially threatening alterations in the security programs surrounding them and enable certain kinds of responsive action to be deployed (e.g. routine aerial surveillance of pipelines that enable the identification of encroaching vegetation or land developments close to pipelines).

Drawing upon the work of Latour (1991), I then proceeded to argue that security performances are *programmed*: they involve the meticulous construction of systems of relations that, through the careful arrangement of network forces, result in the production of particular outputs. Such programs, I have suggested, come into being through negotiations between security actors over their individual interests, with multiple interests coming to be represented in single programs. Security's performance is thus dependent upon the force with which each actor can express their interests within these negotiations.

Using this notion of relational programming, I then built upon it with the concept of modulation that is advocated by Deleuze (1992), demonstrating the multiplicity of programs that can develop across the length of an entities' circulations, and highlighting their potential dynamism and responsiveness. Yet unlike Deleuze, who is critiqued in this thesis for his focus on the assemblages that govern, rather than on the specific transformations undergone by the elements in circulation, here I highlight how such modulations simultaneously involve the transformation of the things in circulation at the ontological level, in accordance with particular kinds of perceived opportunity and threat.

In this way, I offer an account of security's practice that is far more nuanced than reductive narratives of circulatory maintenance and filtration. I provide an analytical framework for studying security that emphasises the way it involves meticulous practices of *transforming* vital circulating elements in order to condition the kinds of phenomenal future that can emerge, and provide a set of tools through which to study the way that particular opportunities and risks are regulated according to the different interests that influence these performances.

Such an approach, I think, has value for critical security studies in four main ways. First, it can inform the way in which we engage with the security performances that surround human bodies. Bodies have often appeared in this literature as passive, unproblematic and immutable. Whilst there is literature on the way that particular kinds of human subject are performed (see Vaughan-Williams, 2015; Salter, 2007), and Foucault's work on the production of disciplined and self-governing subjects has of course been seminal, more attention needs to be given to the application of these techniques in different security contexts. For instance, in reducing airport security to practices of filtration and flow maintenance, we have been left with little impression of how the threatening agency of risky circulating bodies is actually 'cancelled out' or dealt with. Instead, bodies are simply seen to be apprehended, at which point they are 'secure' and are afforded no further attention. Likewise, very little consideration has been paid to the way that different kinds of secured subject are produced in various, constantly changing, ways *across* circulations. Rather than just sorting and apprehending bodies at airport security points, how, for example, are particular kinds of secure circulation performed through dispersed practices such as passengers having particular items removed from their persons at security checkpoints, through seatbelt warning signs being deployed mid-flight; flight marshals surveying and potentially apprehending passengers; blast-proof cockpit doors limiting the capacities of these passengers to compromise the safe operation of the plane; or even through free flight socks being handed out in attempts to cancel out the risk of cases of potentially life threatening deep vein thrombosis? Indeed, whilst there is increasing interest being attributed to security's socio-material performances, limited attention has been paid to security's practices of sculpting and molding circulating entities and the ways through which particular kinds of threat come to be precisely attended to.

Second, this approach provides security scholars with a set of tools for studying in detail the ways in which circulating *materials* are governed at the ontological level across their circulatory journeys, as well as the kinds of threats and opportunity that drive these practices and the ways in which these entities have the capacity to transform and express themselves vitally as they move. Rather than seeing them as simply being filtered, or their circulation being simply maintained, this approach encourages security scholars to appreciate how, just as with humans, materials become subjects of security's practice and are transformed in the process - particular kinds of perceived agency and phenomenal future becoming facilitated, compensated for, limited, and cancelled out. For instance, the circulation of cargo is not simply subject of circulatory maintenance practices (as it appears in the work of Cowen, 2009), but is the subject of a variety of different security practices involving attempts to regulate the conditions of possibility that surround particular kinds of perceived threat. From the deployment of container sealing tags, to the use of x-ray scanners, container ventilation holes, refrigerators for foodstuffs, holograms for determining the authenticity of DVDs and CDs, and the fences, gates and identification cards needed to access port spaces in the governance of cargo, a series of complex socio-technical security apparatuses are constructed around different kinds of cargo circulations in order to ontologically transform these entities in ways that facilitate, compensate for, limit and cancel out particular kinds of perceived future scenario.

Thirdly, this approach may assist security scholars in exploring how security is practiced in relation to intangible entities and 'things', such as data and discourse. What, for instance, might it mean to stay with the trouble relating to the circulation of data? These circulations certainly present unique challenges methodologically, given that it may be difficult, if not impossible, to follow them across their journeys. Indeed, the spaces and scales at which these elements circulate may be radically different to the geographies of circulation that are described in this thesis, with new forms of politics emerging as a result. Yet the way that opportunities and threats are visualized, and the manner in which attempts are made to intervene in their realities, can, I believe, be similarly attended to through such a relational, entity-attentive approach. Moreover, such an approach has particular value here in that it encourages us to examine the dynamic (de)materializations of these elements and the politics that can emerge; from the way that data sometimes materializes in forms such as memory sticks that can get lost, or appears in printed confidential documents that can get photographed. At other times it will travel diffusely through cables and servers as series of binary values. Exploring the possibilities and political situations that come to surround these different ontological qualities and their modes of circulation, as well as the different notions of security that play into them and the ways that they become regulated and manipulated (for example, through encryption, redaction or deletion), could prove a particularly fruitful avenue of future security research.

Finally, I suggest this approach has value for critical security studies in terms of the way it takes seriously the practices of negotiation that inform the construction of security programs. I believe that the expansion of security's referent objects presents a significant challenge for a security literature that continues to distill its outputs into discrete categories relating to single referent objects (for example: national security, global security, economic security, financial security, climate security, social security, environmental security, energy security and so on). Instead of endorsing such distinctions, this thesis requires scholars to closely consider the ways in which different concerns for security interleaf, overlap, and become negotiated. I believe that far more work needs to be done to explore these forms of interaction, from both from a latitudinal perspective (whereby these processes of negotiation are examined at particular points within circulations), and from a longitudinal perspective (whereby the overlaps, synergies, frictions and negotiations that relate to multiple security concerns are examined across the spatial extents of circulations). This, I suggest, invites us to investigate a series of questions. How, for example, do the interests surrounding one point within a circulation, for instance, the collection of competing interests that swell around security's performance in locations where gas is being fracked, come to be balanced against the collection of interests that are located further downstream? Do they become balanced? Whose interests win out? And who and what's security is ensured through these negotiated actions? Moreover, other related questions might include: how do these negotiations affect the kinds of phenomena that can come to emerge? Who and what have their interests represented through these processes of negotiation? And conversely, who and what have their interests excluded? Attending to the political complexity of these security performances and the way that they come to be programmed according to multiple interests, is a much needed avenue for further study.

III. Conclusion: An Entity-Attentive Security Agenda

I have provided in this thesis a series of analytical frameworks through which to conduct future entity-attentive security research. This thesis has looked at the way that security is performed in relation to just one element: natural gas. It has documented a series of strategies through which gas's material qualities present different risks, challenges and opportunities for security, and it has described the ways that these qualities have resulted in a series of specialized techniques to render gas actionable and take action upon it. Yet this is just one study. There is a vast number of other bodies, materials and things that circulate within contemporary societies, and which have yet to be explored in an entity-attentive way. Indeed, whilst Dillon (2005) has described how studies of security have come to be developed around "the circulation of everything", including "every conceivable kind of circulation or flow of peoples and things, of energy and finance, of water and food, of capital and information, of images and discourses, of science and technology, of weapons and ideas, of drugs and of sex (AIDS to prostitution), of microbes and diseases" (p. 2), very little of this expansive literature has actively engaged with the ontological qualities of these various elements, nor have they examined the ways in which their structures come to be transformed through security's practice. From the many other kinds of energy product that are currently in circulation (including oil, coal, electricity, nuclear materials, and water – in both hydro and tidal capacities), through to the movement of other kinds of bodies, objects and immaterial things, there is considerable scope to produce entity-attentive accounts of security that valuably explore the ways in which these elements have aspects of their agency facilitated, compensated for, or cancelled out, across their journeys. As such, we are faced with much work if we are to examine the different troubling qualities of these elements and the ways in which they come to be addressed through security's manifold performances.

Appendix A

List of data sources:

I. Interviews

Date:	Organization:	Role:
21/5/15	Durham Constabulary	*Contingency Planning Officer*
27/6/14	Northeast Ambulance Service	*Emergency Planning and Resilience Manager*
8/8/14	National Grid	*Emergency Operations Manager, Gas Systems Operations*
21/10/14	Northern Gas Networks	*Health, Safety and Environment Manager*
28/10/14	Durham and Darlington County Council (Local Planning Authority)	*Contingency Planning Officer (in charge of overseeing Durham and Darlington Major Accident Hazard Pipeline Emergency Plan)*
3/11/14	DNV-GL	*Orifice Plate Calibration Engineer*
3/11/14	SICK Engineering	*Ultrasonic Flow Metering Engineer*
25/3/15	Northern Gas Networks	*Health, Safety and Environment Manager*
13/4/15	Shell (UK)	*Operations Manager, St. Fergus Gas Processing Terminal*
20/5/15	National Grid	*Energy Forecaster, Short Term Forecasting Team, Gas Systems Operations*
20/11/15	National Grid	*Senior Engineer, Metering*
5/12/15	Durham and Darlington Fire and Rescue Service	*Resilience Manager*
18/12/15	British Gas, Northern Gas Networks & IGEM	*Former Network Operations Director. Also former engineer at ERS. Now Chair of IGEM's Technical Coordinating Committee (which oversees the development of the accepted industry standards)*

II. Site visits

Date:	Location:	Description:
4/4/14 to 6/4/14	Fakenham Gas Museum, Fakenham	*Museum visit and archival research*
27/6/14	Hebburn Ambulance Station - Northeast Ambulance Service	*Half day tour and demonstration of ambulance facilities and resources for dealing with gas incidents*
8/8/14	National Control Centre and National Grid House, Warwick	*Full day tour of National Grid House, including overview of different departments and operational structure. Visited the national gas control room and was given a description of its functions and strategic arrangement. I also received a demonstration of several pieces of gas management software, was taken through NTS maps, pipe by pipe.*
23/9/14	Understanding the Causes of Gas Fires and Explosions, RAF Spadeadam, DNV-GL	*2 day industry training event involving lectures and live demonstrations of different varieties of potential gas fire and explosion*
21/10/14	Northern Gas Regional Operations Office	*Brief tour and overview of the roles of different working groups*
17/11/14	PII Pipeline Solutions, Cramlington	*Half day tour and lectures on 'smart pig' (inline inspection) technologies. Industry event organised by IGEM*
6/2/15	St Mary's College gas engineering works (leak detection) – Northern Gas Networks	*Hour long conversation with network maintenance engineers from Northern Gas Networks, describing methods for ascertaining location of leaks.*

27/2/15	National Gas Museum, Leicester	*Half day museum visit*
8/2/15 to 10/2/15 & 19/2/15 to 20/2/15	National Gas Archives, Warrington	*Multiple days of archival research*
25/3/15	'Escape Chasing' day (multiple locations across the North of England distribution network) – National Gas Networks	*Full day tour provided by the Health, Safety and Environment Manager from Northern Gas Networks. Involved picking up reports of leaks and traveling across the Northeast to the locations where these leaks had been reported. I was then provided demonstrations of how these leaks were located and assessed in terms of the risks they posed, and also how their threats were addressed*
13/4/15	St. Fergus Gas Processing Terminal	*Full day tour of St Fergus gas terminal*
21/5/15	Loughborough Materials and Failure Analysis Centre, DNV-GL	*Two hour tour, including demonstration of the investigation process following fatal incidents*
25/8/15	Neville's Cross mains replacement work, Durham – Northern Gas Networks	*Hour long conversation with network maintenance engineers from Northern Gas Networks.*
3/11/15	DNV-GL Flow Centre, Chilton (including orifice meter calibration laboratory)	*Full day tour and demonstration of meter calibration processes.*
28/11/16	Northern Gas Regional Control Room	*Half day demonstration of the functions and daily operations of the regional control room*

III. Seminars and Industry Briefings

Date:	Title:	Description:
4/11/14	"Constraint Management" National Grid	*Webinar Briefing*
16/11/14	"Emergency Operations" National Grid	*Webinar Briefing*
11/11/14	"Physical Operations of the NTS and Winter Forecasting" National Grid	*Webinar Briefing*
29/11/14	"Pipeline Risk Management" International Pipeline Conference & Exposition, 2014	*Full Day Tutorial*
21/5/15	"Black Dust Revealed" DNV-GL Materials and Failure Analysis Laboratories, Loughborough	*Half Day Seminar*

IV. Conferences

Date:	Conference:
10/6/14	Institute of Gas Engineers and Managers (IGEM) Annual Conference 2014, Loughborough
29/11/14 to 3/10/14	International Pipeline Conference & Exposition 2014, Calgary, Canada
19/11/14	'Don't Panic!' IGEM Southwest & Wales Sections Emergency Planning Gas Conference, Bristol

Appendix B

Sample Interview Extract

Interview with Senior Engineer, National Grid

20th November 2015

Speaker 1: Okay, so great. I was hoping if we could maybe start by talking about your role in National Grid. Are you able to talk through a little of what you do? #00:00:33-0#

Speaker 2: Sure. We are an operational appliance team, and um, the part of the team that I look after we are responsible for full pipe pressure transmission measurement both on and off the system…as a consequence of that work we look after the management of NTS shrinkage…which is the amount of gas that we use for moving gas from the point of supply to the point of delivery. So that's usually terminals and storage sites, interconnectors obviously need to… distribution zones, or direct connect, off takes of the gas. Now we are with transmission, so all of our measurements are done at high pressure. And high pressure to me is anything above 40bar gauge. So it is high pressure. That work means that the team that you have seen is really quite technical. And it's unusual that it is quite young as well, so it's great to be learning that…these skills on that basis, but I have been in this industry mainly from research, I came from research about 15 years ago, and I have always worked on material based research within the gas industry. So I came over here to…for some other parts of the business…I haven't gone back yet, but er…so I started in shrinkage. Shrinkage at that point was merely a function of the amount of compressor fuel we used which is to drive the er, 60 odd compressor sites, sorry 60 odd units, we have 23 compressor sites around the UK for moving the gas from the beach terminals to the point of requirement. Once we had analyzed that initially, we started to reduce own-use gas by better control, making sure that we didn't use the units when they are not actually required, and trying to improve the husbandry or the maintenance of a unit so there weren't the reasons that a control room would run a unit without actually compressing any of the gas, they would only run a unit when they did need it. So there was this reliability issue. So a lot of work was done over the 2000 to 2008 period to improve on reliability and that…the fruition of that is we are seeing about 95% to 98% availability of all units, which is very high. Considering some of them are fairly ancient as well in terms of their gas terminal and design, they are quite mature. But that doesn't matter, we are not trying to fly supersonically…so that doesn't really worry…we are trying to be as effective and efficient as…but they are not quite as efficient as you would probably like. The introduction of dry lonox combustion due to reduced emissions, you've got selective catalytic reduction…all of these techniques are now adding parasitic loads to these guys' engines, so their efficiency is actually going down, although their overall effectiveness in terms of their environmental footprint is going *up*. Which is good. So we have seen a reduction in compressor fuel, but then we started to see a lot of uncertainty around *measurement* that was starting to impact on the overall levels of shrinkage. And shrinkage is a collection of both the gas that you've measured on the system, minus the gas that you have taken off the system. And that bit there is shrinkage. And you say, well I've measured the fuel gas that I have used, I've got a little bit which I know about because of the flow weighted average process which we use to not disadvantage domestic customers, depending on gas source and location. We can then look at usage in the distribution zone, which is usually a small component, and the little left over is unaccounted for. It's not *leakage*, which is…we…all of our system is welded. Or where it is not welded, it is extremely heavily flanged (Laughs) as you can see on the examples just through there! Um, we are not…distribution zones have shrinkage and they have different components within that shrinkage amount. They *will* have leakage because they have a whole collection of different piping structures and infrastructure, er but they also have theft, which we don't. If you are going to tap in to a 50, 60 bar main, well good luck! It's incredibly difficult. We don't see that. We are purely seeing uncertainty in measuring as a consequence of… new metering systems, people not quite understanding the new metering systems, the change in the commercial regime… Because it has come on as the rest of the business has been gradually regulated. We sit there and we are trying to minimise shrinkage for the community because it's a cost which is picked up by everybody who uses the system. It is part of the transportation…what we call commodity charges, which is the transportation charge, in which shrinkage is passed on. A higher shrinkage means that the commodity charge goes up, which means you and I have to pay slightly higher for our gas bill. Because that part is a pass through cost from shipper to the end consumer. So we will reduce that…you know, the costs for shrinkage in 2013/14 were around about 85 million, of which UAG contributed 70-80% of that. Which is quite a high cost. Except that the industry is 20billion per annum. So let's get that in reality. So you know, in terms of er…you and I, 85 million is a huge amount of money…um…but in terms of the overall throughput of the system it is a comparatively small…its top quartile. If you go…all the transmission companies that publish sufficient data for you to make a judgement, we are top quartile. About 0.3, 0.29 percent of throughput. That is very good. That is We've got some American networks, who are the easiest to compare because they have got to publish more and more data, um, they can be anything up to 1.5. I have seen 0.2, but that is probably a very unusual way of them declaring their results rather than…than…so it's not bad. Despite the complexity of the network. But we have to keep it down. We have to keep…and that's what our team does. Its management, its talking to asset owners. We don't own assets, we don't own metering assets sorry, so… #00:07:16-6#

Speaker 2: You don't own any of the meters? #00:07:19-1#

Speaker 1: We own about thirty to be fair, but we are gradually offsetting those as well. But there are over 400 across the whole system and we own thirty. So it's a very small subset of the whole system. #00:07:32-6#

Speaker 2: Mmm. I'm still trying to get my head around the different uses of meters on the system. So you have got fiscal meters, but there are different grades of meters as well, aren't there? What are the purposes of the different levels? #00:07:41-9#

Speaker 1: Yeah there are. Well, as I showed you earlier, the diagram of the development of the network over the last 40-45 years er, you will have seen philosophical changes in how you manage, how you control the network. It's easy to control a point to point network. It's much harder to control a very integrated network, which is what we have now. Um, there was a view early on in the development of the gas industry in a regulators sense, and we are talking about mid-nineties now, um, that National Grid should have a view of what terminals were doing. So we had check metering. So in other words, a terminal would meter, they would tell us what they metered, and outside their door we would have effectively another set of metering. Well, any physicist would tell you, anybody will tell you actually, if you have two watches, they won't tell exactly the same time. Close, but not quite on the same time. And that's what happens with metering. So who do you believe. So check metering had a pretty…I was going to say chequered, but we have had a fairly limited history because quite rightly they could turn around and say I spent X million you know and all this on this equipment. My reading says 20, you say 20.01. What are we doing? Who's right? And you know, both readings are valid within their respective uncertainty. But of course you are talking about huge sums of money. So check metering went away… and check metering was always there to say is…is the uncertainty on that measurement slightly high? It wasn't built to the same standards so it was actually doomed from the start. The industry settled on fiscal measurement quite early on fortunately, so you are measured to a fiscal uncertainty of one percent on volume and one point one percent on energy. And the reason the energy is slightly higher is because you actually calculate from gas composition calorific value. And there is always a bit of uncertainty on your measurement of gas chromatography. So that's why you go to one point one. And that's fine. Everyone accepts that, the modern equipment is more than capable of demonstrating that uncertainty is well inside that. So from a fiscal point of view, that's what we have on the system. We don't have feeder meters. We are a pressure control system. Our modelling, our network modelling, which is run in parallel to the system control, will give you indicative calculations of flow. We are a pressure system so they will be controlling that system on pressure. And that pressure is to maintain the exit point pressures of above 40 bar. That's it. So we do that. And they supply the system to that basis. So metering then, within a feeder meter…a feeder is the bit of pipe that's actually from A to B, that's what we call the big transmission thing of which twenty, thirty-five… …lots of branches off them, but twenty nine big ones. We don't have any meters on them. Mainly because they are a meter at one point, two meters in diameter. That is a huge meter, by any stretch of the imagination, that is a huge meter. That is very expensive. If I say to you look I'm going to spend 50-60 million on a meter, you are going to pay for it through commodity charge and all I'm going to do is make sure that meter's just saying well look I've got some flow in that direction, not that direction. Well you going to say 'mmm. Not sure I'm going to pay for that.' And that's where OFGEM works. You can model it very quickly, very reliably offline, very cheaply. And that is sufficient. You measure…we have all of the measurement points for pressure and temperature around the system anyway, so fine. We are relatively comfortable that we can control the system very safely. #00:11:47-4#

- End of Extract -

Appendix C

Image 1:

Photograph of excavated cast iron medium-pressure gas main, Neville's Cross, Durham (2016)

Image 2:

Photograph of excavated cast iron medium-pressure gas main, Neville's Cross, Durham (2016)

Image 3:

Photograph of inlet facilities at St. Fergus Gas Processing Terminal, Scotland (2014). Gas from drilling platforms in the North Sea emerges onshore from its undersea transmission pipes at this location

Image 4:

Photograph of multiple holes that have been dug in an attempt to locate a gas leak on a distribution main in Durham (2014)

Image 5:

Photograph of example document analyzed as part of this study. Documents in this photograph include training documents, legislative documents, advertising material for devices and assets, and instruction manuals.

Image 6:

Photograph of a live demonstration of a gas explosion at an industry training day at RAF Spadeadam (2014)

Field Note Extract 1:

"Understanding the Causes of Gas Fires and Explosions" Industry training event, DNV-GL's explosion modelling facility at RAF Spadeadam – 23/9/14

"An alarm sounded in the briefing room in which we were receiving a lecture on the kinds of fire and explosion that could develop within gas networks. We all put in the earplugs that had been handed to us, and within seconds, a dull thump shook the room. Some of the pictures that had been fixed to the walls with Velcro tape fell to the ground, only to be immediately stuck back up by one of the event organizers. The lecture continued for about half an hour, after which the group of 20 or so of us (made up of engineers, network operators and investigators for the HSE), were taken outside to witness our final demonstration of the weekend.

We trouped across the muddy ground, passing bits of pipework and testing equipment that were emerging awkwardly out of thick concrete test pads. In front of us was positioned a bright blue shipping container that had been cordoned off with yellow tape. We formed a line along this barrier, distanced safely from the imminent blast. The test was designed to show us the difference between two explosive scenarios. First, a domestic gas explosion, in which the property was vacant, and without furnishings. The second, a similar explosion, but where the property was inhabited and had been furnished. The purpose of this test was to demonstrate how the fixtures within properties interrupted convection currents and thereby forced gas to mix more effectively with the oxygen inside. The result, they claimed, was that the second explosion should be far more powerful, due to the increased number of methane and oxygen molecules that were forced to form relations with one another and a source of heat.

To model the first scenario, the container was filled with a mixture of natural gas and oxygen, the end of the container being sealed with a thick polythene sheet. An alarm then again sounded, warning of an imminent explosion, and the gas was ignited. A ball of flame about the size of a car erupted from the end of the container, making a low 'woofing' noise. Compared to previous demonstrations, this was fairly undramatic.

To model the second scenario, the container was then filled with different objects; bits of pipe, boxes, and crates. It was then sealed, and the same amount of gas and oxygen was introduced to the container. Again, an alarm sounded before the gas was lit, but this time the explosion was enormous. The ball of fire was fifteen, maybe twenty feet long. The noise was deafening, the heat intense (even from thirty feet away), and the pressure wave that was produced tore at our clothes and skin with considerable force. Several participants recoiled from the blast, myself included"

Field Note Extract 2:

Escape Chasing Site Visit Northern Gas Networks – 25/3/15

"Scanning down a print-out of reported leaks that needed to be investigated that day, the Health, Safety and Environment Manager from Northern Gas Networks highlighted a number of incidents. "We will have already missed the FCO's (first call operatives) on these ones", he said as he gestured to the sheet. "But we should be able to get to these other leaks in time to catch one of the guys". Our first aim of the day was to meet up with an FCO to observe how leaks were assessed for riskiness – a difficult task, given that FCOs are constantly on the move, responding to newly reported leaks. We jumped into his car, and drove to the first location. We had missed the FCO (we would later catch up with one at another site), but I was introduced to the engineers attending to the leak. We spoke around one of the holes that they had dug, and they explained what the current job involved. As this leak had concerned gas that could be 'felt, seen or heard' (due to the force with which it was leaving the pipe creating noise, pressing against skin and moving soil), it had to be responded to quickly and could not be left unattended. It had taken a while to pin down its location, due to the gas becoming trapped under the nearby road, and it moving through service ducts under the street (these are used for accessing cables – gas entering them can be particularly dangerous because explosive atmospheres may develop beneath peoples' feet). It was because of these factors that the first reports of the leak had been made over half a mile away."

One of the other engineers then proceeded to describe to me the process of 'bar holing': a technique used for identifying the locations of leaks. This process involves drilling small holes into the ground at equal distances from the approximate location that the leak was reported. A tool is then used to suck out any gas that is in these holes, and a gas detector is inserted to detect the presence of gas. Holes where gas is found to return the fastest provide an indication of the direction from which gas is leaking."

Image 7:

Diagram of pertinent features at the scene of a gas escape in Middlesbrough during an 'Escape Chasing' site visit (2014)

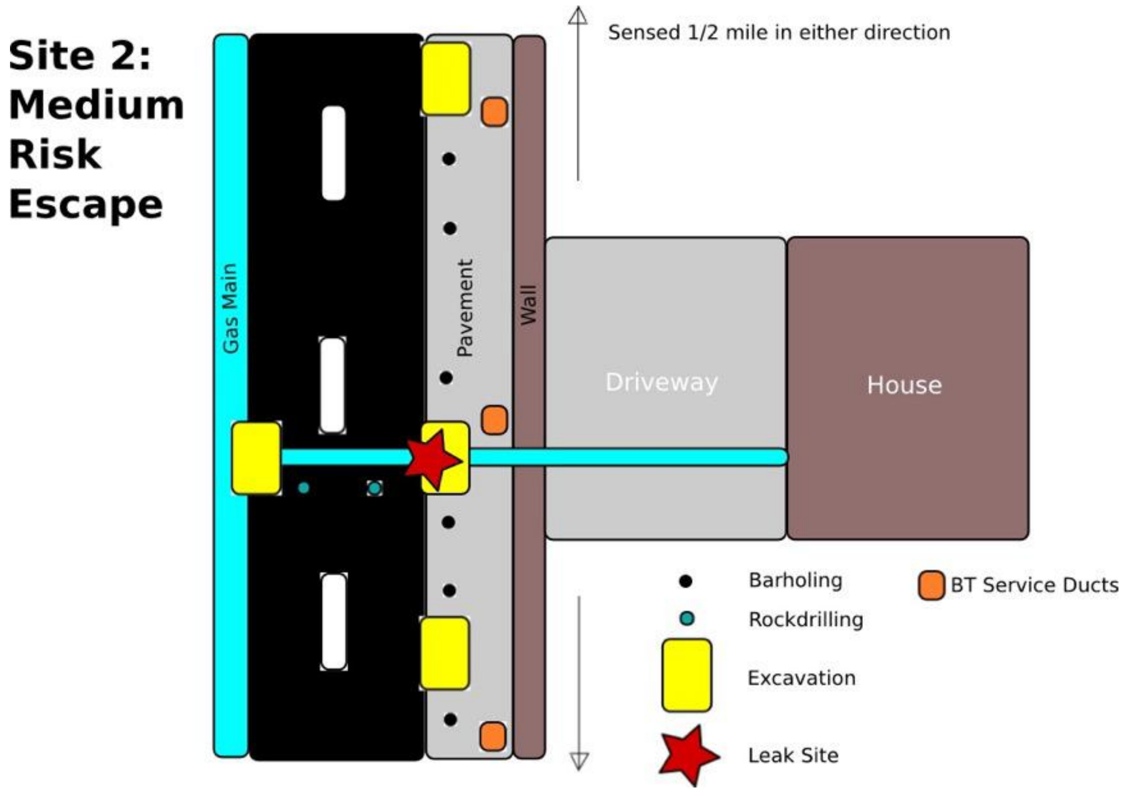


Image 8:

Photograph of an ongoing mains replacement job observed as part of an 'Escape Chasing' site visit day (2014). The polyethylene pipe in this picture has been threaded through the existing iron main observable at the bottom of the picture, allowing these pipes to be replaced without entirely excavating the road.

Image 9:

Photograph of a printout sheet of the risk assessments that have been conducted in relation to reported gas escapes checked that day. Taken during an 'Escape Chasing' site visit (2014)

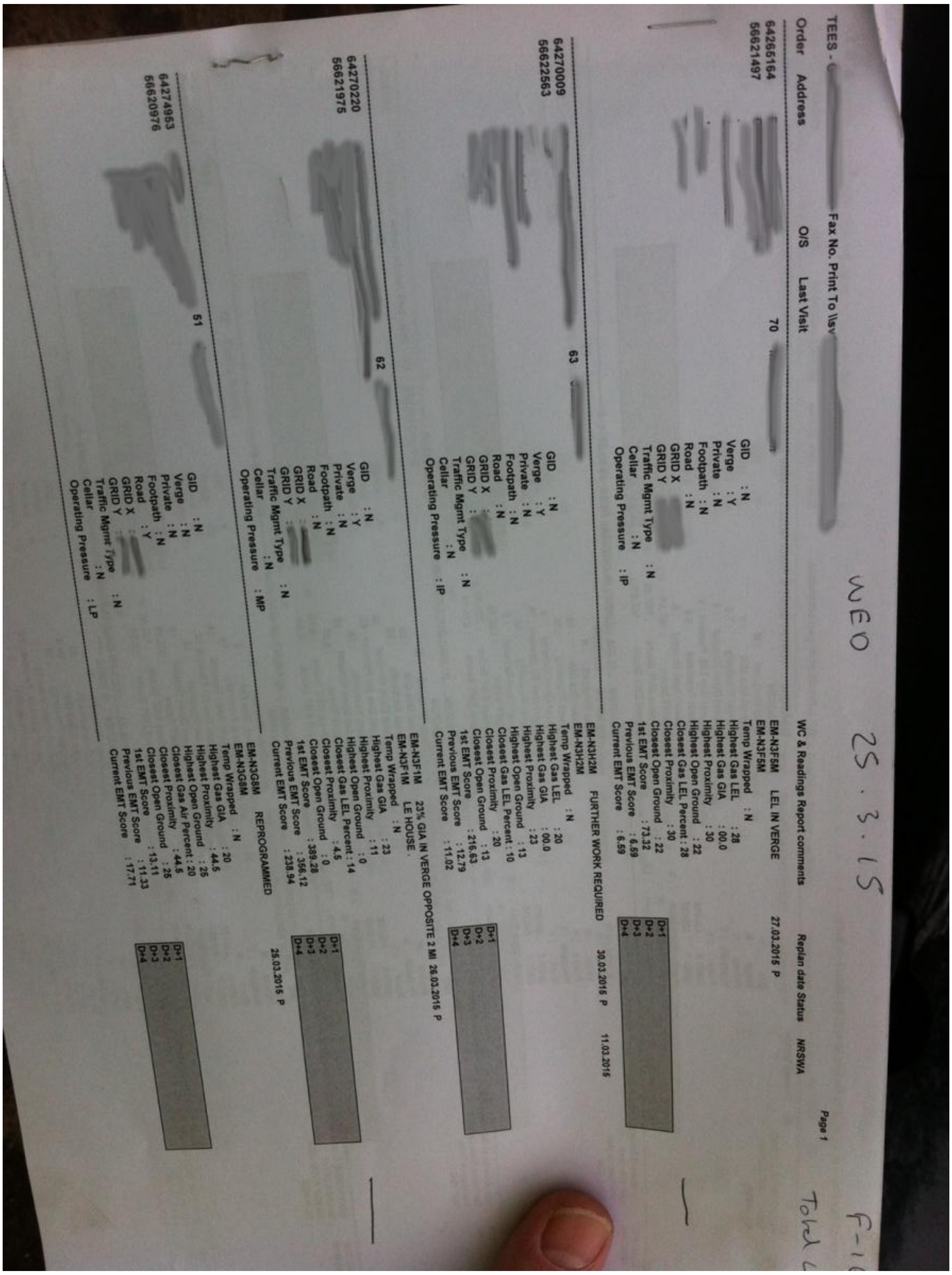


Image 10:

Scan of an email exchange with a Northern Gas Networks maintenance engineer regarding an earlier site visit (2014). Here, the engineer describes how some engineers resort to using divining rods to locate hard-to-find buried pipes.

From: [redacted]
Subject: RE: St Mary's College Conversation
Date: 14 February 2015 at 09:06
To: [redacted]

SM

Hi peter before we complete an escape off we have to do final checks in doing so we located another leak unfortunately we didnt find this in the first additional excavation due to water logged ground the leak was difficult to locate but because we knew the distance between the joins in the pipe due to the previous excavation we were able to step these joins out and dig on them until we located the one that was leaking I hope that makes sense. The divining rods aren't a recognised technique as such but some of the lads do use them to locate pe pipes. Hopefully this answers your queries feel free to email with any more questions

Sent from Samsung Mobile

-------- Original message --------
From: "FORMAN P.J." [redacted]
Date: 13/02/2015 11:15 (GMT+00:00)
To: [redacted]
Subject: RE: St Mary's College Conversation

[redacted]

Great to meet you the other week - it was really kind of you guys to chat away to me for so long about your work. I noticed a few days later that the number of holes outside Mary's College had increased from one to five - do you mind explaining why that was?

Also, were you being serious when you mentioned using divining rods to locate polyethylene pipes?

Hope this finds you well

Best wishes,

Peter

Researcher, PhD

Department of Geography
University of Durham
Science Laboratories
South Road
Durham
DH1 3LE

Telephone [redacted]
Email [redacted]

Image 11:

Map of a section of the North of England gas network at a 1:1050 scale. Maps such as these would be used in interviews to discuss the way that gas travelled and the forms of action that would be taken upon it at different points. Particularly interesting during these conversations would be why certain information was considered sufficiently pertinent to be included on these maps.

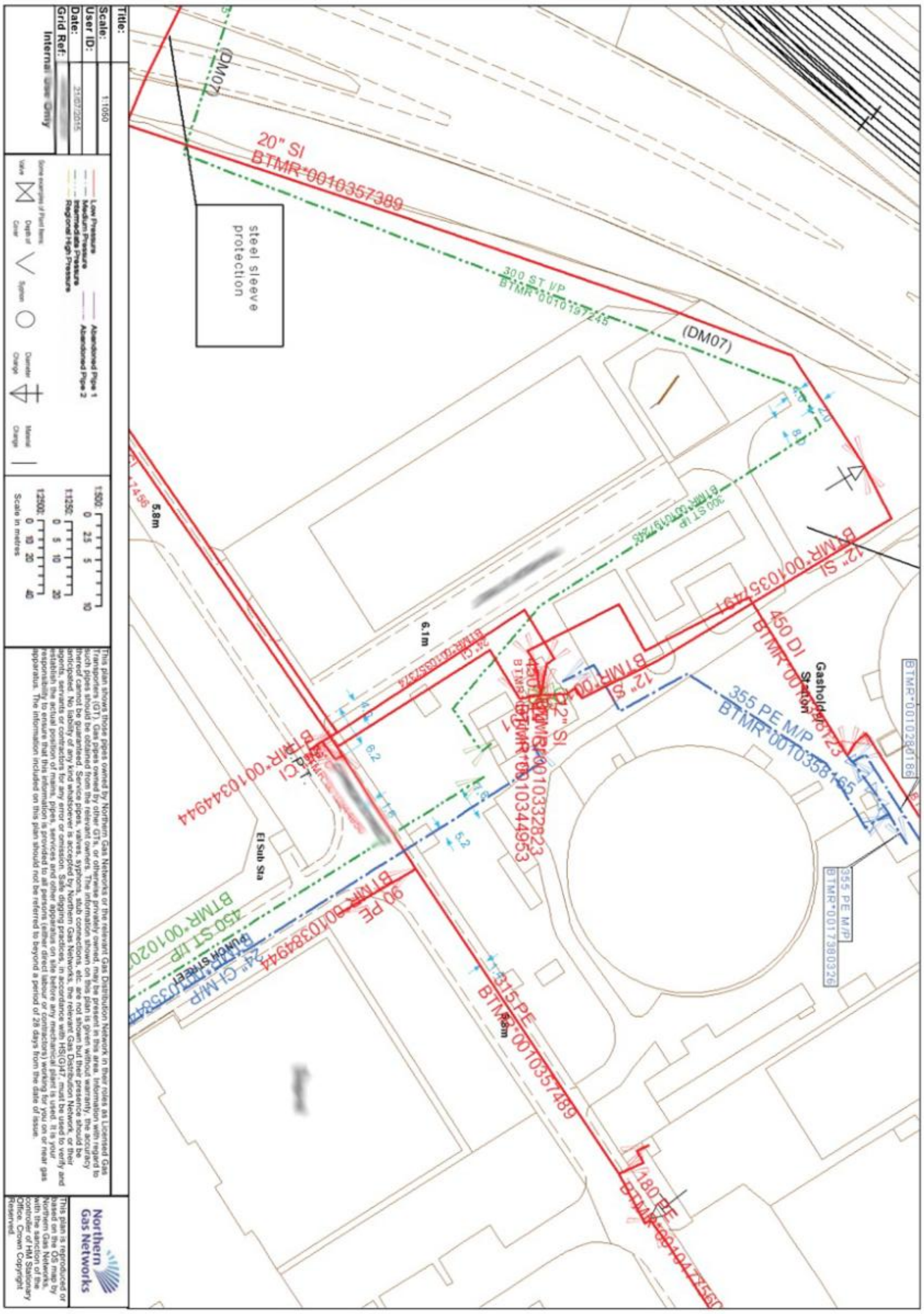
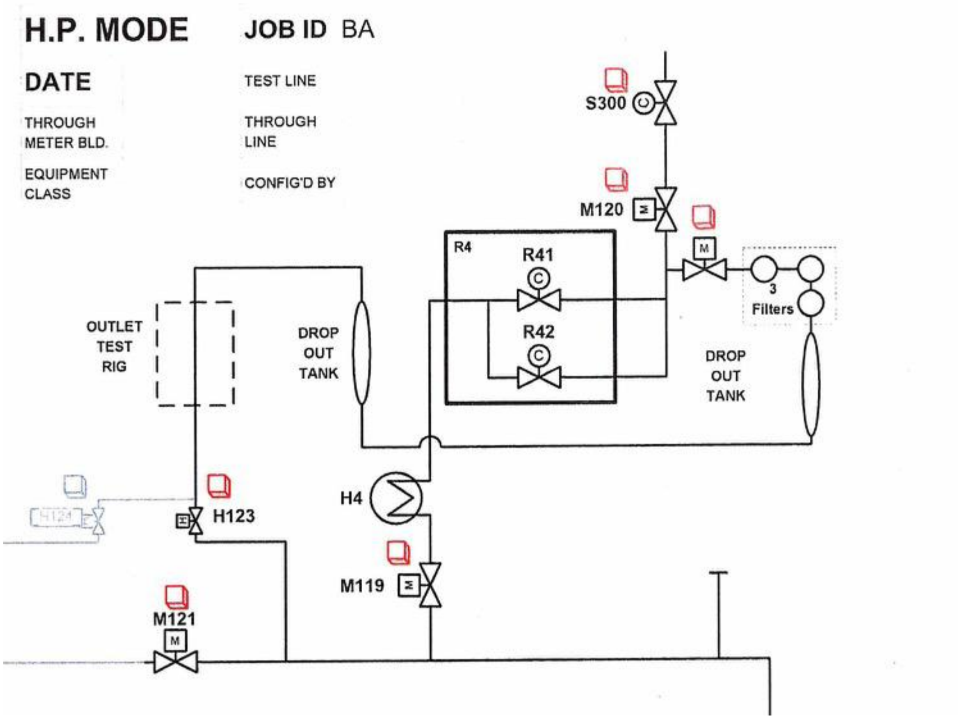


Image 12:

Cropped technical drawing of the arrangements of assets and pipework within a particular gas facility. Maps such as these were useful for observing the small-scale actions that were taken upon gas as it moved through these networks.



Appendix D

Example 'Scratch and Sniff' card

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