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Fuel for commercial politics: the nucleus of early commercial proliferation of atomic energy in three acts

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ABSTRACT

Historical research into the nuclear industry has focussed upon military and commercial aspects of the technology whilst ignoring fuel. This article discusses nuclear fuel, the resource at the centre of the industry and the role superpower politics played in its supply. Starting with the context of superpower competition, we examine the spread of nuclear technology from its beginnings in post-war Britain via West Germany in the 1950s to Finland in the 1960s and 1970s. We demonstrate that each country had varied interests affecting the choice of nuclear fuel for early energy projects; British fuel choices were constrained by its weapons programme and Germany needed legitimacy in the face of opposition in the 1950s. Finland was constrained by 'Finlandisation' and despite domestic enthusiasm the country had to balancing competing blocs in its choice of reactor and fuel. In short, fuel choices were constrained by local and supranational geopolitical conditions.

KEYWORDS

Nuclear fuel; superpower politics; investments; nuclear power station; technology transfer; Great Britain; West Germany; Finland

Introduction

The purpose of this article is to consider how the development of civilian nuclear technology followed different paths and different goals in various zones and periods, and to consider why this process of diffusion unfolded in the way it did. The wider framework of international relations, economic policy, and business connections within this framework are all important contexts for this study. The three cases we are about to present in this article follow the typical model of diffusion from the centre to the peripheries – from superpowers towards smaller, peripheral countries – within the wider frame of nuclear proliferation and the transfer of technology this involved. On the macro-level, this progress describes clearly what happened de facto. Although the number of variables affecting this diffusion (and transfer) is vast, we focus on the fissionable raw materials that had strategic importance as nuclear fuel. We argue that it was the limited availability of these fuels, the underdeveloped market and the high politics related to securing them which greatly affected the diffusion of civilian nuclear programmes especially during the early atomic years. However, the crucial role of

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high politics, and the tight grip of original Anglo-American 'centre'[1] became challenged by the gradual development of various other agents and networks.

In the early years of atomic technology, it was quite widely thought that anyone able to acquire fissile materials or use atomic technology could also produce nuclear weapons applications and therefore be a potential threat to world security (not to mention those states already possessing the so-called atomic secrets). As technical know-how was jealously guarded, even civilian use was a highly political matter related to defence and foreign policy – especially after World War II. International co-operation and technology sharing had to exclude atomic weapons know-how, and even though it was talked up by politicians, not much collaboration took place with regard to civilian uses. In fact, following the war, secret Anglo-American arrangements were made to gain a monopoly or, at least, an oligopoly, on fissile raw materials in the world, and the Americans soon became atomic monopolists – especially in terms of know-how.

Despite these limitations, the commercial use of nuclear technology gradually became more common after the Atoms for Peace initiative in December 1953. Along with the diffusion of technology, the markets for raw materials appeared, and institutions were developed for the diffusion and exchange of information and technology (Hecht, 2012). As Rubio-Varas and De la Torre (2017) have shown, most of the decisions regarding the establishment of commercial nuclear power were made after the Atoms for Peace programme ushered in the so-called Golden Age of Nuclear Power. Nevertheless, right up until the late 1960s, it was the Cold War superpowers of the US and the Soviet Union (USSR) that were the main providers of atomic knowledge, (refined) raw materials and technology.

Atomic technology and resources were inextricably tied to superpower politics and their respective blocs. As we will see, the origins of the technology available for commercial projects depended on the supply of raw materials which, in turn, bound the user to technology transfer, often with a particular bloc in the vein of a politically motivated vendor lock-in. Supply, demand, and the regulation of strategic resources – such as oil, steel, coal, rubber, and tungsten – have been studied extensively in business, economic and political history. However, the aspect of raw materials for nuclear fuel and their effects on commercial developments have been largely overlooked in favour of weapons-related proliferation studies even though the research and design of weapons were ultimately dependent on the very same fuel.

In terms of political history or international relations, matters concerning atomic energy have understandably been approached from the perspective of military strategy, deterrence, and prestige (Dillon, 1983; Freedman, 2003; Macmillan, 1991; Pierre, 1972). Early discussions on proliferation concerned either the Manhattan Project (Groves, 1983; Harbutt, 1986; Herken, 1988) or atomic weapons policy in general and criticisms of it. A synthetic view combining these elements had not been devised until Bayliss's work in 1995. The American side of early nuclear policy – especially concerning use of atomic weapons and its implications – has been covered in detail in terms of the first weapons tests of the early Cold War, various potential conflicts and the taboo of nuclear weapon deployment (Alperovitz, 1996; Boyer, 1985; Gaddis et al., 1999; Harbutt, 1986; Herken, 1988; Sherwin, 2003; Tannenwald, 1999, 2007). These studies have almost exclusively concentrated on the American perspective, and very limited attention was paid to the interests or roles of other states or even 'atomic partners'. The British role has therefore been mostly overlooked, except for studies by Arnold and Smith (2006) and Gowing (1965, 1974) (see also Baylis, 1995; Dillon, 1983;

Pierre, 1972; Roitto, 2015, 2016). Civilian developments were taken up briefly by Bud and Hennessy (2009) and studied in the context of transnational regulatory frameworks (Butler, 2014). Moreover, the history of fissile materials in Britain has not been covered in detail (Berkemeier et al., 2014).

Accounts of the Soviet project are more recent: for instance, the Wilson Center's Nuclear Proliferation History Project has covered new atomic states and nuclear proliferation from 1949 onwards, tending to focus on weapons-related matters, such as the Indian and Pakistani projects (Craig, 2016a, 2016b). There have been other accounts from different national contexts (e.g. Hecht, 1998; Ivaylo, 2014; Kaijser, 1992; Lagaaij & Verbong, 1998; Michelsen & Särkikoski, 2005; Särkikoski, 2011; Voloshin, 2009).[2]

Except for the Case Study Report by Wealer et al. (2018) and the collection edited by Puig (2011), until recently, few academics have used comparative approaches with regard to atomic energy and its civilian development. The editor's introduction in the latter underlines the need for a comparative approach and considers some of the methodological aspects therein: studying development only as technology transfer and neglecting the associated politics and security matters oversimplifies this complex issue. We attempt to address these gaps in this article, and unlike other works, we also keep in mind the dynamics of the Anglo-American relationship and how this affected early regulation of nuclear fuel.

The fact that early nuclear technology was dependent on a market for uranium ore or 'rare ores'[3] has largely remained outside the bounds of business history and technology transfer studies, and yet, it had an important impact on foreign policy too, as it was a key constraint affecting the diffusion of nuclear technology throughout the world. Equally, the path dependency stemming from the initial years of the atomic age and its effect on civilian business have not been given due attention either. This kind of path dependency implies that after making heavy investments in a specific path, any drastic changes from that path become increasingly harder to accomplish (Peters et al., 2005; Schienstock, 2007; Van der Meulen, 1998).

Technology transfer studies, in turn, have covered a multitude of factors, but not nuclear fuel as such, and not in the context of high politics and political economy (cf. Puig, 2008). According to Hymans, (2012, pp. 72–73), greater attention should be paid to the domestic variables involved in the exchange of nuclear technology, as differences between the states can be defining factors. It appears that before nuclear businesses could get under way, securing the supply of fuel, and to some degree, the handling of nuclear waste must be solved first. This meant creating a wider ecosystem, finding experts, funding research and design, making investments, and finding the necessary political backing (Bozeman, 1992, 2000; Donzé & Nishimura, 2014; Jeremy, 1992, 1994). Just as important was solving the acquisition of strategic resources for operating the nuclear plants and developing technology further. Moreover, these aspects demanded closer co-operation with the state before businesses could enter the field.

The challenge, however, lay in the fact that the fissionable raw materials market was underdeveloped or non-existent before the late 1960s (Hecht, 2012), and whatever market did exist was heavily regulated due to security and foreign policy issues, as early atomic research was weapons-related – especially between the US and Britain. Initially, the 'guardians of the new technology' considered placing all potential nuclear raw materials in the world under their joint control. Some states would not comply, but in most cases, the guardians succeeded. Matters changed, however, when Anglo-American co-operation faltered in the spring and autumn of 1946 and the competition on the availability of raw materials heated up globally. The competition now was not only against the USSR – believed to have uranium ore deposits of its own, and to be looking out for more – but also between the former allies. Securing national interests, including possible civilian uses for this atomic technology, became the chosen policy of all nations.

Moreover, during World War II, many of the contractors involved with atomic research projects worked under national governments or were directly overseen by the state, and this arrangement persisted for a while due to national interests and espionage fears. The capital costs of these projects were high enough to impose severe challenges even for states. Moreover, the research and development were highly complex, ranging from raw material acquisition to metallurgical engineering and chemical processing. The need for properly trained scientific staff and other manpower issues complicated matters. Security aspects were also important. The new technology promised great but unknown potential; as Maurice Pearton (1982) pointed out, the Manhattan Project had brought together government, science and industry in a way never before witnessed by the modern world (Buzan & Sem, 1990).

Therefore, nuclear power could be described as politically 'path dependent' on the development of the first atomic weapons. The policies laid out during World War II and directly after it had major effects on how atomic technology was introduced to civilian contexts, especially in the early stages. Against the backdrop of defence and international relations, the new technology and the much coveted potential it was believed to have were highly regulated from the beginning. The Tube Alloys/Manhattan Project was typical of early commercial projects too, given the expensive research, limited availability of specialists, need for high capital investment, considerable development costs and heavy government involvement; the civilian uses of atomic technology were, after all, based on using the same resources, namely scientific knowledge and know-how, as those for the weapon applications. Furthermore, depleted fuel can be used in weapons applications, binding commercial projects (heavy water nuclear reactors, for instance) with military interests, at least in theory.

As was stated above, technology transfer, which was essential for constructing and utilising nuclear power in civilian and commercial uses, can first and foremost be understood as the movement of technology and related information between two parties. The transfer aims to improve at least one party's situation in business, often in terms of competitiveness. The transfer is a multifaceted process and, of course, depends on the nature of the technology, as to whether it will involve the conveying of ideas, patenting and licensing, and personnel acquisition and recruitment, for example. In its simplest form, technology transfer involves the direct purchase of the technology for the purposes of imitation, deconstruction, copying or enhancing. Industrial espionage might also play a role in these aspects (Abramson et al., 1997; Bozeman, 2000; Heslop et al., 2001). The reasons for technology transfer tend to depend not only on the specific local context but also on the development of wider technology. Among the 54 important reasons for technology transfer considered by Heslop et al. (2001, p. 376) are clear identifiable and quantifiable benefits, competitive advantage, novelty aspects, possible future uses and 'inventor champions'.

Availability of essential raw materials or 'atomic secrets' is one example of technology that is difficult to transfer even if there are many incentives to do so. In the case of the early atomic bomb, there were clearly no weapon construction blueprints that could simply be sold, given away or stolen. Creating something that would change the world in unparalleled ways did, in fact, require a very complex process. Among others, Jeremy (1992, 1994), Vernon

(2009) and Vernon and Wells (1966) noted that in most cases, technology transfer happens between two countries, especially if the transfer concerns larger projects, while Rogers (1962) emphasised the role of human capital in this process. In any mobility, the distance between the two points is important. The relationship between Tobler's law (1970) and technology transfer is pertinent here: the closer the two points or participants are to each other, the more they tend to depend on each other or interact. Indeed, Gibson and Smilor (1991) recognised that 'four variables – communication interactivity, cultural and geographical distance, technology equivocality, and personal motivation' are essential elements in technology transfer. Indeed, all the other variables affecting technology transfer depend on them.

Regarding the element of distance – both in political and geographical terms – the US served as the centre for the West, and the USSR, for the East. In exceptional times, and in complex cases however, technology transfer can also take place between locations via various networks (Hughes, 1993; see also Donzé & Nishimura, 2014),[4] as in academic (or in this case, atomic) research in the 1930s. We recognise the need for a more detailed presentation of the technology transfer processes involved, and their various models, but we focus our study on one important element – the availability of nuclear fuel or uranium, and the effects this aspect had on developing the civilian uses of nuclear technology.

The flow of information entailed in multifaceted technology transfer is extremely difficult to control and regulate (Bozeman, 1992; Donzé & Nishimura, 2014). This is especially true with academic information that thrives on discussion and argument. Even if key people could be contained, the diffusion of their ideas could not – the Tube Alloys/Manhattan Project which demanded transnational co-operation proved this. However, if resources essential for research and design could be contained in the Colbertist way (Ritchie & Culver, 2012),[5] which is so often the case with strategic resources, it was perceived that matters could be different if existing raw materials (whether previously jointly held or not) could be secured for the exclusive benefit of the US national project alone. During the time nuclear power and its related businesses were being developed and right up until the 1990s, the capital-intensive European energy industry (and its nuclear component in particular) remained heavily state intensive if not monopolised (Chick, 2007; Hausman et al., 2008; Toninelli, 2000). International diplomacy was needed to acquire technology and overcome the numerous challenges posed by the obvious risks and possible liabilities, and the fact that the business may not earn any profits made privatisation difficult (e.g. Domberger & Piggott, 1986; Parker, 2012).

By shedding light on this past, we can see that it was not simply the technocrats (see Rüdig, 2000) who created the contextual framework (including the business); a variety of agents were involved, namely officials, civil servants, politicians and military men (see Donzé & Nishimura, 2014; Rogers, 1962). In the long run, we can see that the politics which had dominated in the early years started to lose momentum and impetus in response to the gradual development various other networks. Nevertheless, we argue that one of the most important features in early atomic development – from military to civilian uses, from centres to peripheries, and from country to country – was securing the supply of fuel. This aspect, in turn, was related to limitations and regulations stemming from perceived security issues and a country's Cold War alignment. Few countries (initially, the US, and to some extent, the UK and Canada, and soon after, the USSR) had the means for fuel enrichment, production and importing the technology and expertise. These countries also happened to have access to most of the fissile material resources in the world (Hecht, 2012; Helmreich, 1998).

We consider the fuel issue against the backdrop of technology transfer. In this particular case, the transfer was not free but very limited due to various (yet confined) national interests. Although the centre-periphery approach does not capture the complexity of the matter vis-à-vis various contributing agents and elements, it does help to illustrate how mere regulatory attempts did not manage to curb the transfer and that the transfer was more diffusive. The wider abstraction level of this matter can be conveyed via the centre-periphery model (Jeremy, 1992, 1994; Rogers, 1962; Vernon, 2009; Vernon & Wells, 1966), as it is illustrative in terms of heuristics and geospatial mobility. Due to the heavy national interests in regulating the technology (as per our literature review), we chose to analyse how commercial atomic projects developed at increasingly distant points, both geographically and in time, from the US, the world's first country to have a national atomic programme.

We recognise that it was not even the high politics alone that mattered above all; unlike the previous literature, we suggest that the role of high politics in nuclear proliferation in the 1950s and 1960s should be perhaps considered when attempting to understand the complex interactions of various related elements, such as states, companies, markets, scientists, and technological factors, which shaped the outcomes of the various nuclear programmes or even the possibilities of establishing them. The changes, which progressively contributed to making business more important than it had been initially, also contributed to dismantling the government–high politics path dependencies. However, in order to understand these very progressive changes, we must emphasise on the early years and the starting points to a greater extent.

To illustrate the complex dependencies and interdependencies involved with fuel or raw material supply, we consider the above aspects via the case studies of three countries: Britain (1945–1946), West Germany (1950–1960s), and Finland (1960s and 1970s). By presenting simplified versions of their respective national trajectories to develop commercial atomic energy, we aim to (a) shed light on the technology transfer that enabled a more commercial use of atomic energy and (b) analyse how this innovation spread from the 'core areas of nuclear research' to the technological and geographical peripheries by focusing on the progress of the technology transfer on a wider scale and attempting to illustrate factors which contributed to the pace of the progress. Furthermore, we (c) address the interrelation between initial investments in the technology and the availability or scarcity of nuclear fuel, and we (d) discuss the politics behind the business and economics involved at this early stage in the development of the commercial atomic industry to perhaps provide a useful perspective on more recent nuclear dilemmas, too. As an in-depth exploration of these topics is beyond the scope of even a long research article, the focus on fuel availability will serve as the main point of entry.

To understand the importance of fuel policy in these cases, we began with a review of the existing literature on the subject. We tackled most of the available sources and uncovered particular defining works for each country, which we then relied on extensively. As matters related to atomic projects tend to be highly political, relying on a particular specialist historian for each country is actually a strength of this study, as it ensures that nothing related to the topic will be omitted by oversight. Our angle is also quite comparative, not because the chosen three countries are fairly comparable, but because it allows us to cover all the particularities and national contexts which relate to the focus, namely how fuel was secured for atomic power production. From there on, to fully uncover the trajectory of nuclear power history, we supplement our knowledge of fuel politics with original sources, such as parliamentary material, committee reports, committee archives and, to some extent, the records of certain companies. Based on these materials, we then build the case reports that specifically assess the fuel-related issues at the heart of atomic technology development for civilian use in each national context and the technology transfer that this entailed. Finally, we summarise the empirical findings in a discussion and draw our main conclusions about the importance of fuel policy in commercial atomic projects. Although our choice of historical approach has limitations, it enables us to uncover the diffusion of civilian nuclear technology in Europe. Between them, the three cases chosen here cover the Golden Age of Nuclear Power.

Britain (1940s): forced independence and path dependency

As a point of reference, Britain provides an interesting and enlightening example for early developments, as it was one of the first states to pursue atomic capability – at least semi-independently (Pierre, 1972, pp. 1–6). Since Margaret Gowing's official histories, few studies have focused on the British development of atomic technology. Those that do provide a limited or oversimplified understanding of Britain's role (see Dillon 1983, pp. 1–6; Roitto 2015, pp. 13–36). Most works focusing on Britain have covered atomic technology as a source of prestige, and technology transfer studies also view this aspect as such, of strategic advantage, or a mixture of both (Baylis, 1995; Dillon, 1983; Pierre, 1972; Puig 2008).

Atomic research advanced quickly in the 1920s and 1930s. Britain was, in many ways, the leading state in theoretical atomic research at this stage. However, the development of atomic weapons and technology was otherwise very much a transnational affair and benefited from research conducted internationally (Gowing, 1965; Wieser & Settle, 2001). During this time, the increasing price of coal was becoming a problem for Britain. The inability of energy production to meet the growing demand and the capital costs involved in building expensive power stations meant that the pace of technological change started to slow down by the late 1930s. Research and design was not the main interest within the industry, even among the leading companies, and finance capital for investment was lacking. Instead, technology was improved by simply purchasing more advanced systems or machinery and using them in prototype trials. If efficiency improved, then the solution was to purchase more of the same equipment. The British electricity industry in this period was also rather fragmented, and it remained so until it was nationalised in 1948. Wartime and post-war inflation added to the challenges of devising and constructing new technology and plants (Harlow, 2018/1977, pp. 54–55; Morgan, 1984; Wilson, 1995), but during the war British companies and their research counterparts were given some help by the government. Imperial Chemical Industries (ICI) was one of the firms that benefited from government research programmes (Edgerton, 2005/1987). During the war, the British government undertook the centralised production of certain goods and conducted research through state-owned enterprises, laboratories and universities. Private industry worked for the government (Edgerton, 2005/1987; Millward, 2000; Wilson, 1995).

The start of the British atomic project is depicted in some detail by Gowing (1965, 1974). Knowledge about the new technology that was uncovered by research conducted by four universities was eventually collected by the Ministry of Air under supervision of the MAUD Committee and conveyed to the Americans. After some tug of war, Winston Churchill, Franklin D. Roosevelt, and MacKenzie King met at the Quebec Conference in 1943 and signed an agreement there to begin a joint research project between the US, Canada, and Britain. In 1944, a supplement to the Quebec Agreement (dubbed the Hyde Park Aide Memoire) was also agreed between Roosevelt and Churchill; it stated that the co-operation was to continue after the war and that it was to be full and effective. A Combined Policy Committee (CPC) was set up to co-ordinate the project, and the Combined Development Trust (CDT) was then established to control the acquisition and allocation of raw materials, namely uranium (Fakley, 1983; Gowing, 1965, 1974, p. 6).

In exchange for the immense costs that the Americans were shouldering for this, Churchill had agreed to give them the rights for future patents related to the commercial use of the new technology (Hyde Park Aide-Mémoire, printed in Gowing, 1965). The raw materials, acquired with the help and efforts of the British, mainly from the Belgian Congo, were to be shipped to the US under the auspices of the CDT. All three signatory states had the rights to use the raw material, but as the Manhattan Project was a joint venture and almost all research was conducted in the US, this effectively meant that all the resources went there. Britain was focusing on other research, such as radar and the jet engine, and the results of these projects were shared with the Americans. In exchange, the British thought they would receive full information about the atomic research, but that was not the case. The Americans were already vehemently guarding the atomic secrets during the joint project (see, for instance, Groves, 1983; Norris, 2003, p. 335; Roitto, 2015, pp. 200–206, 226–228, 273).

However, the British had continued with domestic atomic research on a small scale throughout the time the joint project was underway. ICI worked on the Tube Alloys Project along with government laboratories and universities. Private industry typically operated under government subcontracts, a policy adopted since the 1920s (Wilson, 1995, pp. 171–172, 174). Metropolitan Vickers was involved in designing and building certain prototypes for Professor Peierls' gaseous diffusion research and design; however, this equipment was soon swapped for simpler technology. Vickers was also involved in heavy engineering, and along with Thompson Houston and General Electric (not the US company), it worked as a government subcontractor, taking on electric and electromagnetic work. Other subcontractors for the British government included Lund Humphries and Sun Engraving (which focused on printing technologies related to graphite research), and Mond & Nickel (which specialised in metallurgy). All these companies' roles were, however, rather limited or isolated (de Wolf Smyth,[6] 1946, pp. 274–280; Gowing, 1965, 1974; Jones, 2000, pp. 32–33).

ICI, itself born out of a government-induced merger, played quite a significant role in the British nuclear programme (when the Tube Alloys Project had not yet been subsumed into the Manhattan Project).[7] Banks claimed that uranium manufacturing processes used in the early days of the Tube Alloys Project were developed by ICI (Banks, 2000, pp. 1–2), while Edgerton (2005/1987, pp. 91–92) maintains that in World War II, '…ICI bid to take over civil nuclear power: by 1944 it had spent £8,70,000 on nuclear research, paid for by government'. According to Gowing (1965), one part of the project was to produce uranium industrially but on a small scale, a result of the MAUD Committee days of 1940 and 1941. As the process raised complicated metallurgy- and chemistry-related problems, a pilot plant was established in 1943. However, expansion was required to continue the research, and this was not pursued further due to the Quebec Agreement.

ICI was the only company considered capable of developing atomic technology after the war. Indeed, ICI was offered a government contract for the Tube Alloys Project and a role in devising possible future civilian uses, but it declined several times and continued to do so after the war, the main reasons being the likelihood of government intervention and the fact that such involvement would have affected the other activities of ICI.[8] It appears that the government found it easier to recruit and borrow leaders from the private sector instead. However, after the war, even this became challenging, as the government's prerogative in making others work for it was no longer valid (Fakley, 1983; Gowing 1974).

Post-Hiroshima and after the war, it was very clear to the British that they needed to pursue the new technology further. This technology could not only be used as a weapon – a source of prestige and strategic advantage – but also offered possibly limitless potential. Parliament was excited about these possibilities,[9] as Britain had suffered greatly in the war and was struggling economically, and a fuel crisis affected electricity production (Bullock, 1984; Morgan, 1984). At this time, most of the electricity in Britain was produced from coal (Warde, 2006, p. 69), but in terms of atomic technology, especially militaristically, Britain was still a leading state and very much at the centre of the new technology.[10]

When Clement Attlee's Labour government came to power, it decided to follow a specific foreign affairs trajectory, but once informed about the wartime atomic collaboration with the US, they soon embraced the policy adopted by Churchill. Britain wanted to become a state with atomic capability; indeed, it wanted the atomic bomb soon.[11] To save time and do this as cheaply as possible, the first option was to continue pursuing the wartime policy[12] (Gowing, 1974; Roitto, 2015). However, the scarcity of fissionable raw materials was one of the major problems.[13]

Britain had already considered pursuing atomic capability independently during the war, but because access to the raw materials was difficult and ending the war was the biggest priority, it was decided that the best option would be to work together with the US to devise the 'winning weapon'. As time progressed, the calculated cost of breaking free from the agreement and conducting research experiments on her own were judged too much for the British economy, as the facilities required (that were currently supplied by the US) would have had to be built from scratch in the UK at great cost. As per the estimates, about 1200 people would have been required just to set up an enrichment plant at a time when limited money and resources were needed elsewhere. The plant alone would have cost the price of a full-scale battleship (approximately £60–70 million in 1943 currency), while any further project was estimated to require a workforce of at least 20,000 (Gowing, 1965, pp. 162–164). Moreover, if transatlantic co-operation stopped, the high-grade uranium that the British had procured from the Congo, and was now in the US, would be lost too.

Almost all the uranium for the Manhattan Project and the very high grade uranium ore had been acquired by the British in South Africa and from British contacts in the Belgian Congo, respectively. When France fell in the war, Britain acquired all the heavy water known to exist in the world – some 300 litres – from French refugee scientists and sent this material to the US as well. Besides these losses, the political consequences of breaking up the Anglo-American collaboration could have been detrimental for Britain in general (Gowing, 1965, pp. 56–60). The political ramifications of these decisions would soon be seen in other ways, however, underlining the importance of political aspects in the initial stages of atomic development.[14]

Indeed, much to Britain's surprise, the US stated in the autumn of 1945 that they had no record of any agreement about future atomic co-operation. However, when the British sent copies of the Quebec Agreement and Hyde Park Aide Memoire, the Americans found their copies 'which had been filed incorrectly'.[15] Simultaneously, it soon became clear to Attlee's government that there was too much to gain and that much had already been invested for Britain to abandon the transparent foreign policy promised in their manifesto.[16] The Labour government thus opted for a two-headed foreign policy to both honour this promise and pursue the wartime realism of the secret co-operation with the US begun during the war. This also meant reinforcing her dependency on past decisions and investments in which the US had the upper hand. Only after much political pressure did the British finally secure a chance to negotiate about continuing the collaboration: they were promised full and effective co-operation in the future, but with only ad hoc arrangements that were eventually never ratified (Roitto, 2015, Chapter 5).

> The three Governments will take measures so far as practicable to secure control and possession, by purchase or otherwise, of all deposits of uranium or thorium situated in areas comprising the US, its territories and possessions, the United Kingdom, and Canada. They will also use every endeavour with respect to the remaining territories of the British Commonwealth and other countries to acquire all available supplies of uranium and thorium. All supplies acquired under the provisions of this paragraph will be placed at the disposition of the Combined Development Trust.[17]

The Washington Agreement also promised resources would be allocated according to need, while surplus would be stored to be allocated in the future on a fair and equitable basis.[18] In practice, it meant all resources would be shipped to the US.

In the Washington negotiations, the Americans now showed great interest in the idea they had just denied the British – international control of atomic energy and sharing information suitable for civilian uses in the future – and the British supported it as the agreement seemed to uphold resource oligopoly.[19]

In the early autumn of 1945, Attlee made a statement before Parliament that Britain was also researching atomic technology, not just a bomb. In part, this was also a stratagem to get the reluctant Americans to continue negotiating about collaboration. The Americans were thus warned in advance that the government was 'forced' by parliamentary pressure[20] to issue a statement[21] about having gained atomic knowledge during the war. Historian Arnold Toynbee was recruited to monitor any public discussions about atomic matters and to follow up on any reports pertaining to finding sources for fissionable raw materials; Britain needed to secure these for either the joint or independent atomic projects.[22]

Although Britain's independent atomic project was rather delayed because of high politics, it was finally underway.[23] Britain certainly wanted the know-how and technology, but the project required raw materials. Attlee's 'bomb committee', GEN 75, met three times after November 1945. It decided in favour of large-scale plutonium enrichment, initially in experimental piles, with the clear aim of making an atomic weapon.[24] Further help from the Advisory Committee on Atomic Energy (ACAE) helped coin the domestic project. ACAE acted as a consultant committee reporting directly to the Prime Minister (PM), and its tasks included keeping him abreast of international atomic affairs, especially with Anglo-American co-operation in mind. More important in this case though was the fact that ACAE was also set up to investigate the domestic implications of the new technology and to advise the government how best to develop it in Britain, both for military and civilian purposes.[25] Most of the project costs were buried under the Ministry of Supply figures (Gowing, 1974, pp. 48–55).

The main plan was to continue secret co-operation but with a focus on developing Britain's own atomic capability, mainly the weapon, and to prevent others from acquiring the means to achieve this – especially the raw materials. This could be done either institutionally – through the United Nations (UN) – or by attempting to secure a monopoly or oligopoly with the US. It was hoped that the Americans would feel motivated to continue co-operating under the CDT arrangement now that new uranium ore deposits had been found in South Africa.[26]

As these plans went against the government's publicly stated policy and could have led to a public outcry, the government attempted to keep all parliamentary questions about atomic raw materials off the floor by concluding a secret extra-parliamentary arrangement with the opposition. The Leader of the Opposition, Winston Churchill, agreed to this as he also believed that making any information about these scarce resources public would endanger both the British project and Anglo-American co-operation.[27] In preparation for the joint and independent projects, Britain had actually scouted around for potential deposits of the raw materials around the world. The CAB 126 series (of minutes and papers) reveals that a detailed state-by-state review of possible sources of raw materials was conducted. Many countries were listed across several continents, including Sweden, China, the USSR, Brazil, Czechoslovakia, Honduras, French Morocco, and the Belgian Congo. The earliest of these records mention the Congo (1943) and Brazil (1944), and the majority of the other dedicated records were established from the spring of 1945 onwards.[28] The most important of these sources turned out to be the Congo, which delivered raw materials for the use of the CDT (Berkemeier et al., 2014; Gowing, 1974).

However, Labour MPs were harder to restrain in practice than the executive had hoped, and questions were asked on all possible aspects of atomic matters, including the acquisition of raw materials in spite of the secret arrangements made.[29] Concerns were also voiced about focusing only on the weapons potential of atomic energy despite the existence of an acute energy crisis that it could potentially solve.[30] A more detailed account of the struggle between Parliament and the executive, and the tug of war between Britain and the US over the promise of secret atomic co-operation has been outlined by Roitto (2015, 2016).

Certain companies[31] were enlisted as the British atomic programme progressed. Most of them helped construct government facilities. However, because of weapons-related secrecy, interest in pursuing government contracts waned, especially as the work would have taken them away from other ventures more aligned with company strategy. Profitable civilian uses for atomic energy were seen to belong of the distant future (Fakley, 1983; Gowing, 1974).

Although these companies had the necessary expertise, government funding was limited to begin with (Edgerton, 2005/1987; Horrocks, 1999), and thus, only a handful of their experts offered technical advice to the sub-committees, the majority of which consisted of politicians, military men, scientists and certain civil servants. The agency model was very much in use due to the political entanglements and weapons-related emphasis demanding government guidance (Gowing, 1974; Millward, 2000), whereby companies had to submit to the potential patents belonging to the state, which could also ultimately decide about any possible use of the technology (de Wolf Smyth, 1946, p. 284). Therefore, the government played a strong role irrespective of the eventual use of the technology. 'Nuclear power, like nuclear weapons, would remain firmly in the province of public agencies […]' (Edgerton, 2005/1987, pp. 91–92).

After a successful autumn in 1945, the British project faced several severe challenges. Not only were the private companies reluctant to take part in the project, but atomic relations with the US had deteriorated. The co-operation that had been promised by the Americans did not materialise, and yet British resources kept flowing into the US. Meanwhile, the international UN control plan, a 'Plan B' of sorts, was not making any progress either despite having gained initial backing from the USSR. Importantly, the US seemed to be leaning more towards the path of developing a true monopoly, and thus, it followed suitable politics to that end even though the raw materials and certain British specialists were clearly still important to them (Gowing, 1974; Roitto, 2015).

Britain pushed back by making numerous attempts to replace the Groves–Anderson Memorandum (which had only ever been a stop-gap measure), as full-scale assistance was needed to build Britain's own piles for research and production. More importantly, all information related to military applications was required, and in return Britain would continue to pool resources.[32] However, the negotiations with the Americans to replace the CPC and CDT arrangements were unsuccessful.[33] At this point, the British considered securing raw materials for the independent project despite the CDT arrangement still being legal. The Commonwealth had been charted earlier for resources for the purposes of the joint Tube Alloys/Manhattan Project, and other potential locations were kept in mind too. For instance, attempts to secure a potential uranium supply from Cortes, Honduras, had been made before Christmas 1945, but British officials had warned that if the find there proved to be valuable, the Americans would move in fast.[34]

Among the Commonwealth locations was South Africa, which had delivered some material earlier, but it appeared that they were not so keen to co-operate with Britain this time.[35] Securing a reliable raw material supply had now become an issue whether or not the Americans were involved, as the ad hoc arrangements the 'allies' had in place would not suffice for the British. Indeed, going behind each other's backs would be considered good cause for liquidating the CDT arrangement and reallocating raw materials among the signatories.[36] As it was, on 17 February 1946, the British CPC delegation was informed that the US preferred to halt secret co-operation altogether.[37]

The British Nuclear Physics Subcommittee demanded a wider nuclear physics programme now that co-operation with the Americans was petering out.[38] Planning for this intensified as the breakup of the CPC became formal: Foreign Secretary Ernest Bevin informed PM Attlee about British plans to discuss possibilities with other countries in the Commonwealth; Canada had opted for bandwagoning with the US. Bevin thought that setting up an atomic plant in Victoria Falls in Southern Africa was a worthwhile idea[39] even though the British had not been able to secure the raw materials for nuclear fuel from South Africa despite leading General Groves (the American in charge of the Manhattan Project) into thinking that they had; thus, they would have had more to offer in the event that the secret co-operation had continued.[40]

However, while searching for a source of raw materials for either eventuality, the British had overlooked Article XIV, Paragraph 102 of the UN Charter which they had dutifully signed along with the majority of signatory states in the autumn of 1945. It required that any new agreements considered as an alliance – such as the 'full and effective' co-operation secretly agreed to by Britain and the US – be published for all to see. The Americans pointed this out as a reason for discontinuing co-operation – the atomic plans could not be made public.[41] Furthermore, the British government was bound by the Washington

Declaration and the Moscow Declaration, which agreed that the future of atomic regulation be placed under the UN's mandate. Even if it was possible to navigate around the UN, the political pressure from Parliament to abide by international law was too great (Roitto, 2015).

In April 1946, President Truman informed the British that the CPC's request for full information on construction and operation of atomic energy plants in the US with the intent to build and operate one in Britain had been denied.[42] The British responded by demanding co-operation from the Americans; otherwise, the CDT would be terminated and the raw materials would be shipped home.[43] The strategy was good in theory because the US was still dependent on Britain and Canada for raw materials despite possessing the most advanced technology for development and refining. In 1945, not a single uranium mine existed in the US (Mahaffey, 2010, pp. 183–190), and the CDT supply was even more important to the US, as their intended supply source for raw materials, the 'Daniels Pile', was not showing any results[44]. Conveniently, for the Americans, the Belgian government surprised the British by stating that they would also be obliged to publish the previous secret arrangements about the Congo deliveries. If they had become public, Attlee's government may have been faced with a vote of no confidence. As the British withdrew their threat to ship the raw materials home, the domestic pressure against the Belgian premier, Henri Spaak, mysteriously disappeared too.[45]

The Acheson–Lilienthal Committee in the US had recommended placing raw materials under UN governance until safety guarantees could be devised, and this too would have meant losing all future resources. Furthermore, forthcoming domestic legislation in the US was to prevent co-operation as well.[46] Acquiring raw materials was, in fact, a more pressing problem than acquiring the technology or making the existing technology work (Gowing, 1974, pp. 103–105, 118–119). Thus, a compromise was devised. All the fissile material they had received from the Congo up to and including 31 March 1946 would stay in the US; thereafter, it would be divided equally. With regard to the technology that the Manhattan Project had acquired from Tube Alloys, the British demanded 15 tons of metal uranium and 50 tons of oxide (from the Mallinckrodt Company), but the deal never went ahead[47] and Attlee's appeal to Truman fell on deaf ears.[48] According to Bevin, there was no point in Britain committing to international control plans either, as they would surely jeopardise the independent atomic project.[49] Therefore, Britain called back all her leading scientists from the UN, as they would be needed at home.[50]

While the secret co-operation lasted, the US, Britain, and Canada had agreed that they would attempt to jointly map out and control all 'fissile' fuel sources in the world, and they almost succeeded at this with regards to uranium and thorium. Several months before co-operation stopped, it had been noted that the commercial side of atomic energy ought to be considered too, which only made the matter of securing raw materials all the more pressing. In the case of the Congo, using force was mooted as a means to keep hold of raw materials, but memos from the British ACAE concluded that no form of control would be 100% effective, especially as the estimations of the amount of resources required for the weapons project varied from 85 to 900 tons. Thorium had been found in Travancore (India), Brazil and Netherlands East Indies, and these resources were about to be secured in co-operation with the US.[51]

After February 1946, the British tried to secure their supply from Travancore while they still had an imperial advantage, and to keep it secret from the Americans, who were also interested.[52] Were Britain to succeed in this, the plan was to process the material back home, but in case this was not possible, the local authorities were also to be given the vague promise that plants would be established in Travancore. This promise was not made with any serious intent though, due to concerns about technology proliferation.[53] Eventually, thorium research was abandoned, however, as it was not suitable for weapon projects. Indeed, this discovery could have hypothetically contributed to West Germany abandoning a plan to develop Light Water Reactors (LWRs) later.

Three reactor models were considered in the independent British atomic project; the selection depended on raw materials availability and the cost although the dire economic situation did not diminish the need to develop an atomic weapon. Natural uranium enrichening was considered difficult and time-consuming, and sources for U 235 and U 233 became increasingly scarce as the Cold War gathered pace (Hecht, 1998, 2012; Helmreich, 1986, 1998). Plutonium was more cost-effective, but Britain lacked the equipment and expertise for exploiting it. As the ore supply from the CDT was very limited, Britain opted to develop technology that used natural uranium. The Windscale Nuclear Facility in Sellafield, Cumbria, was fully operational by 1951. The high cost of the independent project was tolerated because of the potential weapon applications; any other use was seen mainly as a by-product of producing weapons-grade fissile material. Windscale focused on producing weapons-grade plutonium, because this was up to 10 times more cost-efficient (Gowing, 1974, pp. 165–167) than producing enriched uranium (HEU). The capacity to produce weapons-grade plutonium was achieved in 1951, which led to the first British nuclear test in 1952. Domestic production of HEU, however, was only started in 1953–1954 in Capenhurst.

Calder Hall, in Cumbria, became the first industrial-scale nuclear power station in the world, but it was far from commercial, as the civilian uses for atomic technology clearly depended on the raw materials and technology being used primarily to produce weapons. The British had begun with a head start in research, but failed to produce any technology that they could sell for quite a while (Gowing, 1974). Later attempts were limited due to nuclear diplomacy regarding Britain's special relationship with the US (Krige, 2006, 2011; Mallard, 2014) and the Anglo-American–Canadian resource agreement (CDA[54]) which also favoured the Americans.[55] One option also considered at this point was to acquire more raw materials from Portugal, and a British government agency was tasked to enquire into the matter. In 1951, a further acquisition attempt was agreed with the Dutch in 1951, but it came to nothing. The British attempt to sideline the CDA – the successor to the CDT – failed (Berkemeier et al., 2014).

The paradox of Britain at the dawn of the atomic age was that the country was dependent at every level on past co-operation insofar as any further commercial development of atomic power depended on high politics. The country had a head start in atomic development over all other states, but it got cut off from US technology and know-how, losing most of its CDT resources in 1946, after which point there was no chance of securing any turnkey tenders or other technology transfers. The main goal of the British project was to enrich fissile materials for an atomic weapon, focusing on cost effective plutonium technology (gaseous diffusion). However, the US remained somewhat dependent on British supply by proxy, which meant that in the end, Britain did regain control of some of the CDT resources, and she remained otherwise politically and economically aligned with the US. These examples certainly indicate Britain's gradual decline from the centre to the periphery, and the subsequent context in which atomic technology and resources would develop in the following decades. The availability of the fuel was an essential factor, which in turn depended to a great extent on politics. This aspect was underscored by the fact that the kind of more diverse network suitable for a more diffusive transfer of technology, resources, or both had not really been established yet, but was only starting to emerge. Thus, the regulation attempts related to high politics were also more efficient, and in turn, limited the progress of the technology.

West Germany (1950s–1960s): benefits of the atoms for peace project

Before the beginning of World War II, the electrification rate of Germany was quite high. The technological revolution allowed by this abundance allowed large companies to diversify their research and design projects; innovations became institutionalised, and national and international networks were established to foster more progress (e.g. Amatori & Colli, 2011, pp. 135–145). As a former enemy state, West Germany's economy remained under allied control until the late 1950s. Of course, this limited the state's options during the most intensive period of reconstruction, while arms and related technologies and businesses were regulated even more heavily. The German 'Energy Industry Act' of 1935 (*Energiewirtschaftsgesetz*), which already enabled the state to control industrial investments, caused some scrutiny in the private sector after the war (Radkau, 1998a, pp. 176–179).

After the war, despite privatisation interests, the West German economy was still being regulated at the federal and individual state levels, and this continued until unemployment levels had dropped sufficiently due to the economic growth stimulated by international subventions and investments. In general, the state's direct ownership of businesses at this time was governed by West Germany's federal budget regulations, especially if the area of business had political implications or was crucial to the state's interest. Electricity was one of those key areas of business, and consumption of electricity was expected to rise heavily now that the German economy was focusing on the energy-hungry industries of chemicals, metals, and machinery manufacture among others. Out of the nine West German electric companies providing power for industry, four were totally owned by the state, and the state owned more than 50% of 4 others, giving it many possibilities for guiding business. The RWE company (*Rheinisch-Westfälisches Elektrizitätswerk AG*) was an exception; the state owned less than 30% of it. In general, West Germany had the technological and scientific infrastructure capable of fostering and developing research and design in high technology (Bellini, 2000, pp. 44–46; Wengeroth, 2000, pp. 107–109, 120–121).

The creation of the European Coal and Steel Community (ECSC) aimed to support European industries by helping them to modernise. The establishment of Euratom was also related to this aspect. The European energy mix, like that of West Germany's, leaned heavily on coal, but overproduction was causing severe difficulties and a slump in prices. Dependency on fossil fuels was alarming, and cheap energy was essential for stable production and keeping production costs down. New technologies and a booming economy also required more electricity, and atomic energy offered one possibility. Joachim Radkau stated that the euphoria surrounding atomic power was not only due to the motives of the electricity industry or its customers (not to mention the business conglomerates who were both) but also because the utopias themselves fed the urge for acquiring atomic technology, as did the prestige it was seen to have for a state in control of this new technology (Matthes, 2000; Radkau, 1983; 1998a, p. 189; see also Hecht, 1998 and Roitto, 2015).

Germany had played an important role in early atomic research. In the 1930s, however, many prolific scientists left the country as the Nazis came to power (e.g. Gowing, 1965; Lee, 2006, pp. 160–166). During this era and World War II, those German scientists who had remained in the country worked on projects for military applications (Augustine, 2018, p. 25; Powers, 1993). After World War II, those same scientists who had been working for German research and development projects were highly sought after by the Americans, Russians, and British as a valuable source of expertise. Operations with names such as ALSOS, PAPERCLIP, BIG, and EPSILON were aimed at recovering all of the nuclear secrets and resources the Germans possessed (Groves, 1983). The Soviet atomic project, for instance, benefited greatly from German know-how (Oleynyakov, 2000).

After the war, the Federal Republic of Germany (FRG) was denied the right to research and develop peaceful uses for uranium, refine or enrich fissionable materials, or construct nuclear power facilities (Corbach, 2005). The country's intentions had to be first approved by the Western Allies and, to this end, civilian purposes were emphasised by the government over all others. West German politicians, fronted by the Chancellor, appealed for permission to initiate nuclear research and promised extremely heavy supervision and transparency in future projects as well as abstention from all weapons-related activity.[56]

As the country was in post-war ruin, the economic resources and manpower for a national atomic project were absent. East Germany was home to uranium deposits, as the Soviets had already found out – since 1946, the USSR had run a large-scale uranium mine called Wismut, which became the most important source for nuclear fuel in the Eastern Bloc (Augustine, 2018, p. 200). In comparison, the FRG had practically no known uranium deposits, which was one reason for the late development of the Fast Breed Reactor (Marth, 2011, p. 153). Atomic fuel would thus affect technology demands. Self-reliance, or sovereignty, as Hecht (1998, 2012) called it, was seen as a strategic issue for the national economy. The mineral reserves in the Black Forest and Fichtelgebirge areas were insufficient to provide for a large-scale nuclear programme, and there was concern that the existing nuclear weapon states might use up all the existing deposits in the world for their military purposes (Marth, 2011, p. 153).

In 1955, the Western powers gave the FRG permission to begin developing atomic power for civilian use. The federal government established and funded large research centres to study the various possibilities of transferring and implementing nuclear research. An extensive network of universities was put to work on this, though they were modelled along the lines of the large national research and design laboratories in the US and Britain (Abramson et al., 1997, pp. 312–314). In general, this type of research on nuclear energy was one of the first contexts for total cost of ownership calculations (Abramson et al., 1997, pp. 221–222), although restrictions in calculation capacity at the time meant that only a few variables could be taken into account. However, as will be shown, this type of analysis was evident in the German considerations and the Finnish case.

For the Americans, contributing to German, French and other national projects was also a way of regulating the development of any potentially competitive technology by offering affordable atomic solutions and raw materials to trusted allies who, to save resources, would opt for US technology rather than develop their own. It also provided the US with a revenue and served as a political means to hinder any wider-ranging European nuclear projects such as Euratom (Whitesides, 2019, pp. 75–82).

With the considerable help of US manufacturers, West Germany started to develop its first commercial nuclear plants. Siemens/Westinghouse developed a 'pressurised water-reactor' or PWR (Radkau & Hahn, 2013, pp. 49–51), which, unlike the other reactor types, was unable to enrich uranium to produce fissile material suitable for nuclear weapons (Feiveson et al., 2016). The technology was rather new at the time, the first commercial nuclear reactor connected to the power grid in the US, Shippingport, was also a PWR. However, the reactor used there was not a typical example of a commercial PWR, as it had originally been intended for use in a US aircraft carrier.[57]

As in Britain, some of the private businesses in West Germany were wary of Bonn's requests to invest in the atomic programme. The possibility of conflict arising between a business and the state, enforced by federal legislation, caused some alarm. Energy consumption would have had to rise drastically before RWE would have considered atomic energy an economically worthwhile option (Radkau, 1998a, pp. 176–179, 188–193). For a long time, lignite coal, for example, was seen as being easier to acquire and better suited to RWE's strategy. However, atomic power did offer one benefit over coal, namely the possibility of location-independent power generation, thus allowing transport costs to be ignored. The electricity-hungry chemical industry could, for instance, avoid the transport costs of shifting coal and importing oil, and thus, chemicals took the lead in the nuclear economy. Economically, as the price of fossil fuels rose, atomic energy would become more feasible and new fields of business would open up with the promise of continuous economic growth (Marx, 2015, pp. 7–8, 27–28). Raw material supply and costs were thus important factors for business even if the arguments related to them were based on presumptions to some extent.

As Radkau and Hahn (2013) discussed, early on, West Germany could choose between British and American models of atomic policy. This choice affected the kind of fissile fuel that would be needed (natural or enriched uranium), which in turn dictated the reactor type to be developed and all the other technological factors associated with it. In this respect, the fuel determined all other aspects. As the main target of the British reactor project was not electricity generation but the production of weapons-grade plutonium, West Germany was obliged to forsake natural uranium and look to the Americans instead, although using enriched uranium would, of course, mean dependency on the US. Eventually the Atoms for Peace campaign persuaded the West Germans, and they adopted the light reactors on offer because they could not produce weapons-grade fuel. Heavy Water Reactors (HWRs) or related projects were not so readily available either (Whitesides, 2019, pp. 75–82). West Germany also opted for a Boiling Water Reactor (BWR), which was set up by General Electric (US) and AEG (FRG) in a joint effort, leading to the first commercial BWR to be established in Kahl in 1961 (Radkau & Hahn, 2013, pp. 47–51).

The first dedicated West German atomic programme (*Atomprogramm*; *500-MW-Programm/Eltviller*) began in 1957. The main emphasis of this programme was to develop a German reactor instead of relying on an imported model. It was to be an adaptation of American and British designs (Radkau & Hahn, 2013, pp. 107–108). A similar kind of naturalisation happened in France (Hecht, 1998) and – to a lesser degree – in Finland, as we shall see. The decisions about the German designs were made with limited (if any) political regulation (Nelkin & Pollak, 1980; Rüdig, 2000, pp. 49–51) as the federal government was eager to not fall behind. In February 1957, the Minister for Atomic Matters, Siegfried Balke, argued for the need to import uranium since establishing German uranium mining would require too much time,[58] but the West German nuclear industry's desire to be independent of the US remained constant. Accordingly, the Fast Breeder Project began in April 1960 at the *Kernforschungszentrum* in Karlsruhe (Marth, 2011, p. 153). Siemens eventually developed a type of HWR there that used natural uranium as a fuel and thus was no longer dependent on the enriched uranium from the US (Radkau & Hahn, 2013, p. 181).

Despite the high politics most certainly required in international relations to secure support, during the 1940s and at the beginning of the 1950s, the role of politicians in West German atomic development was rather limited. They were important in creating a suitable ecosystem for private business, which then accomplished the rest. The field was dominated by atomic experts supplied by an extensive network of universities well versed in research and design (Radkau, 1983).

The West German interests were civilian in nature, as were those of Finland. Both states had historical baggage due to them being or siding with the aggressors in World War II, which meant even stricter regulation of armed capability, which in turn made others especially wary about Germany's nuclear plans. However, the similarity ended there: in 1955, West Germany joined NATO (which Finland could not). Moreover, West Germany signed arrangements for hosting US nuclear weapons, as did eight other NATO countries that were part of a wider US security strategy (Kristensen, 2009). Thus, West Germany did not need to devise its own deterrent but could reallocate its resources instead. In comparison, Britain had no such option and had to put the heavy costs down to a question of national security.

In the early 1950s, the federal Minister of Finance Ludwig Erhard and the management of RWE and Siemens advocated that the government play only a very limited role in supervising the development of atomic technology in West Germany (Radkau & Hahn, 2013, pp. 94–98), but by 1955, the Ministry for Atomic Matters (*Bundesministerium für Atomfragen*) was established to regulate atomic developments in the FRG. This led, as in many other countries, to the Atomic Energy Act in 1959.

The manner in which this bill was prepared reveals interesting issues. At the ministry level, political impetus built up in debates concerning atomic technology even though there were no reports of any accidents until 1957. The number of queries and government initiatives about the topic gradually increased. However, overall, the discussions showed that the government knew they could not avoid using the technology, and the regulatory measures would remain limited since it was, after all, West Germany planned to use the technology for civilian use only. However, regulations pertaining to security and safety would, of course, be required.[59]

It was important for the West German industry to show a commitment to Western trajectories of wider nuclear technology development. No doubt, the possibility of technology transfer was also in the minds of those industrial actors caught in what would, these days, be called technological vendor lock-in. West Germany's atomic policy was a civilian one, and the prestige aspect of military nuclear capability was absent. This aspect and the missing strategic angle can be explained by the heavy emphasis and public pledges about the peaceful goal of the German project. However, these declarations did not matter; the more the technology spread and the knowledge about it increased and was discussed, the more urgent the need to establish regulation became.

The first experimental nuclear reactor in West Germany that was connected to the grid went live in 1960. It had a capacity of 16 MWe. The major difference between this reactor and others in the world was that this prototype pebble bed reactor, known as an AVR

(*Arbeitsgemeinschaft Versuchsreaktor*), used thorium-based fuel (Nuclear Power in Germany, 2018). The British had considered this reactor type briefly in 1945–1946, but it was abandoned almost immediately when it became clear that it would not produce weapons-grade fuel too (see above). However, for the FRG, this aspect was irrelevant, as the country focused on using atomic power for peaceful means anyway. The subsequent commercial adaptation of the AVR, the 300 MWe THTR (*Thorium Hochtemperatur Reaktor*), which was planned for construction from the 1970s onwards, could use thorium, but it mainly used U-235. THTR was a costly operation, and the commercial prototype was only utilised for a few years. However, it played a very important role in terms of increasing and enhancing nuclear capacity and skills in Germany.[60]

In an interview in 1965, Hans Michaelis, Director-General of Euratom, stated that West Germany's uranium would have to be imported. Canada, the US, South Africa, and Australia were selected as potential suppliers even though Australia had been reluctant to sell (Hecht, 1998, 2012) and Canada supplied the US and Britain (Gowing, 1974). In comparison to oil producers in the Middle East, uranium suppliers seemed much more reliable. According to Michaelis, only about 10% of the costs in atomic energy plants are attributable to fuel, whereas these costs could constitute up to 60% of the total when using oil. Moreover, the total amount of nuclear fuel required was rather moderate, thereby pushing down the transport and storage costs as well. At the time Michaelis gave his interview, only 1% of the European Commission's member states' energy consumption was provided by nuclear power. In Germany, 85% of energy consumption was attributed to coal. Although the electricity produced by the early nuclear power stations was more expensive (due to the heavy initial investment costs), this was about to change as more efficient technology was already being developed. Although Michaelis recognised that the EC member states were not able to construct profitable nuclear plants in the ongoing 'first phase', the co-operation among the industry, electricity companies and nuclear power companies had already made the technology more cost-effective. The scale of the nuclear projects was, however, huge, and Michaelis observed that of all the electricity companies, perhaps only RWE would have the means set up a nuclear power station without the need for external contributions. Smaller companies would have to resort to co-operation, as nationalisation of electricity was unlikely in the FRG. The costs had to consider construction, fuel, training, operating and other expenses. Jointly owned plants might provide the solution, as had been already done in Obrigheim, with a 280 MWe plant (Michaelis, 1965, pp. 340–343).

Meanwhile, AEG's rapid rise to prominence in the nuclear energy business had been helped by its work with General Electric until 1973. The same was true for Siemens, which had not renewed its licence with Westinghouse in 1970. Apparently, the technology transfer had worked well enough (see also Hatch, 1986, pp. 82–83).

Due to a steep worldwide increase in oil prices in 1973, the federal government started to consider nuclear power as the chosen form of energy production, and massive investments were planned. Already in the summer of 1969, the major players in the German atomic industry, *RWE der Kraftwerk Union AG* (*KWU*) and *HOCHTIEF AG*, pre-signed a deal on the largest nuclear power reactor (capacity: 1200 MW) to be constructed outside the US (Radkau, 1998b, pp. 224, 229).

Finally, in the 1970s, only after considerable reflection did RWE opt to pursue atomic power and become a major player in the atomic lobby, which had been important for some of its competitors for a while. RWE's close ties to the chemicals industry, especially to BASF (which wanted but could not have its own nuclear power station for energy production), was important in this regard (Marx, 2015, p. 8, pp. 27–28).

In 1977, the Wyhl Anti-Nuclear Protest Movement grew ever larger in West Germany, arguing that maintaining nuclear power production was not really economic because of the dependency on fissile raw material that had to be imported from remote, possibly non-aligned sources, such as the USSR (Augustine, 2018, pp. 98–100). Then again, as atomic power became more politicised and criticised throughout the 1970s, the technology transfers which had already been made had also been nationalised and refined. Thus, Western Germany and its business conglomerates became major players in the nuclear power business, posing a challenge even to companies based in the US.

The Finnish case (1960s and 1970s): balancing between the East and the West

In terms of atomic capability and related technology transfer, Finland was very much on the periphery (Jeremy, 1992, 1994; Vernon, 2009; Vernon & Wells, 1966). The interest in atomic technology became evident only in the mid-1950s and manifested as part of a wider international 'atomic enthusiasm' (e.g. Matthes, 2000; Rubio-Varas & De la Torre, 2017; Schmid, 2015, pp. 120–122). Having been on the losing side in World War II, international regulation and dependency on the politics of the past were evident in various ways – especially regarding strategic technologies or resources. The Paris Peace Agreement of 1947 specifically denied Finland from acquiring nuclear weapons too, and the Finns had constantly emphasise that they were only interested in peaceful applications (e.g. Jauho, 1999, p. 96; Laurila 1962, p. 4). Formally neutral or at least non-aligned, Finland was not part of either superpower bloc. However, the international connections concerning the Finnish case have remained elusive.

The main focus was on energy needs; there was no interest in developing a military programme (e.g. Särkikoski, 2011). The Finnish economy was going through rapid industrialisation in the 1960s, and there was a pronounced need for more energy as well as advanced technology (e.g. Hjerppe, 1988; Jalava, 2003; Myllyntaus, 1991). In the past, electricity production had been based on hydroelectric power, which was reaching its maximum capacity. This meant that a formerly energy self-sufficient country was rapidly becoming an importer of fossil fuels (Michelsen & Särkikoski, 2005, p. 41; Myllyntaus, 1991, pp. 130, 210; Ranta, 1993, p. 412; Ruuskanen, 2019, pp. 253–255). At this point, the most hopeful proponents were picturing a limitless form of energy. However, Finland's would-be 'nuclear policy' was co-ordinated by a state-appointed Energy Committee, which sought to analyse the issue from a more moderate perspective in 1956. 'Due to the alarming decline in our country's total energy resources and the steady increase in the need for energy imports', the report ran, 'we should also pay attention to the potential that atomic energy can provide us in the near future' (Energy Committee, 1956, p. 8).

As in other countries, the pursuit of self-sufficiency was an important starting point for the Finnish government's energy policy (Energy Committee, 1956, pp. 19–20). To achieve this, a natural uranium-based technology was considered in the first nuclear power plans. There were several benefits: the fuel source could probably be found in Finland, a complicated enrichment processes (which would have required other expensive investments[61] and dependence on other countries) could be avoided, and plutonium – believed to be a desirable commodity to possess – would have been generated as a side product.

Finland's soil was largely granite-based (similar to Canada's), and the prospects for finding uranium were thus considered good (Larsson & Hyyryläinen, 1962, p. 137; Laurila, 1962, p. 6), and unlike the US (where uranium resources had been nationalised), the Finnish state allowed private companies to engage in a free-for-all quest to find them.[62] Nevertheless, the state-owned electricity company *Imatran Voima* (IVO) and state-owned mining company *Outokumpu* carried out some test mining, and by the late 1950s, they had already managed to enrich a small amount of pure, reactor-grade uranium oxide. However, the project did not progress to the industrial scale; this development was carried out by a private company, *Atomienergia*, which started a small uranium mine that remained operational from 1959 to 1963. The company had been set up by private industry[63] that wanted to be involved in the construction of atomic energy in one way or another, despite its lack of expertise in related technology. Before Atomienergia was closed for being unprofitable, the mine produced some 30 tons of yellow cake uranium concrete. This product was, however, sold to Sweden[64] (Laurila, 1967, pp. 188–189; Michelsen & Särkikoski, 2005, pp. 44–45).

Although the uranium reserves found were not particularly rich domestic resources, they were thought to be sufficient to maintain a few power stations for some years. The idea of using these or preparing them for potential use was intended to ensure a continuous fuel supply in case foreign supply was cut off. This notion resonated with the traditional way of thinking about energy self-sufficiency (Räisänen, 1962, p. 128; Ranta, 1993, p. 413). Gradually, however, the idea of purchasing already enriched uranium was considered increasingly attractive, especially as enriched uranium was now available in the global market to be used for peaceful purposes due to the advent of the Atoms for Peace programme in the mid-1950s. This may have softened the prejudices associated with depending on imported fuels. However, as was soon to be discovered, it was difficult to get price estimates, and purchases were not possible without foreign policy commitments being made (e.g. Michelsen & Särkikoski, 2005, p. 41).

As is usual with acquiring advanced technology, those with more limited resources, such as the Finnish state, will try to allocate them as efficiently as possible, to avoid overlapping projects. Universities, other state-owned research and design institutions and private companies tend to get recruited for these efforts (e.g. Poutanen, 2014). However, unlike the case of Britain or Germany, parliamentary coverage of the matter appears to have been rather limited, and atomic power in Finland remained very much a subject for the executive and industry at this stage. Atomic affairs were initially controlled by the government's Atomic Committee, established in 1955 on the suggestion of the Finnish Academy's Nobel prize-winning foreman, A. I. Virtanen. The Finnish industry was also interested in privately funding an atomic power station that would serve the rapidly increasing energy needs of industry, particularly Finland's biggest industry, forestry, which was quite energy intensive.

The original aim of the Finnish Atomic Project was to acquire the knowledge needed to keep pace with international developments and to start a domestic nuclear power project, although acquiring atomic technology would also have been prestigious for a small state with limited resources at its disposal (Baylis, 1995; Dillon, 1983; Sine et al., 2003). Given the need for a co-ordinating body to prepare, among other eventualities, for international agreements, a permanent Atomic Energy Committee (*Atomienergianeuvottelukunta*) was formed in 1956. It played a significant role in the first nuclear power project. In addition to technology and domestic fuel sources, the delegation concluded international agreements and negotiated, inter alia, the availability of enriched uranium and the terms of delivery. Discussions were held not only within the framework of international organisations but also in direct bilateral negotiations during various visits to Canada, the US, and the USSR.

The Finnish project began at a time when several countries wanted to start selling nuclear power plants. The major nuclear powers were eager to market their commercial technology to Finland (e.g. Laurila, 1967, pp. 321–322). Besides revenue, atomic trade also brought techno-political prestige to the seller, who would then be credited as the frontrunner of the technology. This was well understood in Finland too, which recognised that the purpose was to tie countries through technology co-operation to their own sphere of interest, just as British and Canadian options were forced to be closely bound to US policies during the Manhattan Project. Indeed, the USSR used its nuclear technology to bind Eastern Europe in the same way (see Schmid, 2011, 2015). According to Laurila (1982, pp. 98–101), the Finnish delegations were thus extremely careful not to commit directly to any schemes or plans without being given time to fully consider them.

The Finnish delegations were interested in Western technology and fuel supply, which would preferably be organised through international organisations such as the International Atomic Energy Agency (IAEA). However, during the negotiations with the Americans, it became clear that the price of enriched uranium would not be determined by the market but by the US authorities in co-operation with the Pentagon. In practice, this meant that the price would be influenced by world politics and the needs of various research and armament programs.[65] Between 1945 and 1946, Truman's administration initiated attempts to reduce the US military's influence on atomic matters, but by the mid-1960s, the arms race was in full swing, and the US was building up its nuclear arsenal. As the attempts to regulate international nuclear development for peaceful ends had already failed once due to competition between the major nuclear powers, thereby affecting the plans for UN regulation, there were no guarantees that the Atoms for Peace plan would succeed; sudden changes in geopolitics could jeopardise fuel supply.

Finland concluded that as it was already dependent on fossil fuels from abroad, it was economically and politically dependent on suppliers of nuclear fuel too (e.g. Laurila, 1962, p. 28). As we have already seen, Britain and West Germany were atomically dependent on the US, as was France, which imported technology from the US and benefited from Westinghouse's expertise and then Gallicised it (Hecht, 1998, 2012, pp. 68–69). These dependencies were also linked to varying degrees of political alignment with the US. This implies that alignment orientation was not the most crucial question; otherwise, they would have opted for Soviet technology. However, for the Finns, leaning towards either of the superpowers still posed a dilemma.

The Finnish Atomic Energy Committee eventually suggested that as the fuel-related policy was unpredictable, decisions should be made solely on economic grounds (Laurila, 1962, p. 28). The 'dawn of the atomic age' was over by the end of the 1950s (Gowing, 1965, 1974; Matthes, 2000; Roitto, 2015, 2016), and the initial international enthusiasm for nuclear power was waning.[66] However, by the 1960s, its competitiveness was seen to have improved, especially if built in very large units. As predictions showed that the energy demand would at least double in the 1970s, nuclear power began to seem viable for electricity generation in Finland (Nevanlinna and Tuuli, 1962). In some ways, it also promised less dependency on external suppliers of energy or raw materials, which was especially attractive for a country that already suffered from a heavy trade deficit and dependency on imported fuels. Most of this dependency arose due to the need for oil, and the repercussions were felt when the oil crisis hit in 1973. It may well be that referring to economic factors as the guiding principle was a tact political decision, as in the case of Germany.

The first report considering the construction of nuclear power stations in Finland was made in the late 1950s in close co-operation with the IAEA. The subject of the review was a rather small unit (150–250 MW) that was planned for construction in the late 1960s, but then in April 1963, the Atomic Energy Committee made the more substantial proposition of building an actual nuclear power station. At that time, interest was still focused on natural uranium reactors, with encouraging examples from Canada (Wealer et al., 2018, pp. 148–148) and other Nordic countries (Michelsen & Särkikoski, 2005, pp. 44–45; Ranta, 1993, p. 413). Co-operation with Atoms for Peace added credibility and transparency to the Finnish project's legitimate aims too. In the mid-1960s, state-owned IVO and General Electric from Canada designed a 275 MW HWR. The plans were carefully drafted to the point of completion, and this experience would later serve IVO in good stead when explaining the reasoning behind its eventual choice as Finland's first nuclear power station.

The Finnish electricity industry experienced conflicts between state-owned companies and the private sector (e.g. Ruuskanen, 2019, pp. 149–252; Särkikoski 2011; Vesikansa, 2004). In addition to economic conflicts of interest, the ideological tug of war over the right to operate in that market was ongoing. It was common knowledge that the energy-intensive private forest industry in particular had made its own plans to utilise nuclear power as early as the 1950s (e.g. Hellström et al., 2013; Särkikoski, 2011, p. 129). The leader of the Social Democrats later argued that given the importance of securing energy supplies and the long-term risks associated with nuclear energy, the political Left felt the state was obviously responsible for the construction of nuclear power plants (Sorsa, 2003, pp. 302–303). Most importantly, the project of the state-owned company IVO started first.

IVO's invitation to tender was issued at a time convenient to the buyer; sales of commercial nuclear reactors had become more common from 1963 onwards and were boosted by the emergence of American LWRs (Särkikoski, 2011, p. 156). In fact, in the mid-1960s, according to Särkikoski (2011, p. 44), Finland was probably given the widest selection of nuclear power stations to choose from than any other country in the world. The only major atomic power that did not submit a tender was France. IVO's intention was to order the power station as a turnkey delivery.

Meanwhile, the 'uranium market' was starting to change too, and enriched uranium could now be purchased more freely from the world market as supply and demand became nationally, internationally, and supranationally systematised (Hecht, 1998, 2012; Helmreich, 1986, 1998; Kroenig, 2009). Although the Nuclear Exchange Corporation (Nuexco) was established only in 1968, it did not totally bypass certain states' roles (Hecht, 2012, pp. 56–66). Nor did it completely open the market. The global competition that did exist in these opening markets was fierce, however, leading to a 'yellow cake cartel' and heavy increases in the prices of raw materials in the 1970s (Hecht, 2012, pp. 68–70, 77; Taylor & Yokell, 1979). For some at least, enriched uranium was not the only kind of hyper-strategic military resource, but usually, states with advanced technology jealously guard their advantages. By deregulating and sharing technological advances, they would have more to lose than gain in terms of competitive edge (Kroenig, 2009). Geopolitical aspects caused volatility in the uranium market too, which has been the case ever since the dawn of the atomic age.[67]

IVO's invitation to tender (issued in July 1965) was thus open to plans for both types of reactors (Michelsen & Särkikoski, 2005, pp. 56, 75, 79). The three best tenderers were announced the following spring. They were AEG from West Germany, Canadian General Electric, and Westinghouse from the US. The choice seemed to be based solely on the technical and economic evaluation of the power stations, but many experts also paid attention to fuel supply considerations. The Canadian option used natural uranium, but the other two operated with enriched fuel, which was only available from the US, the USSR, or Britain. However, Britain's production was so small that it was not a realistic option (Laurila, 1967, p. 267; Michelsen & Särkikoski, 2005, p. 85). As per Westinghouse's offer, the fuel would need to be purchased from the US, but for the AEG reactor, the fuel issue would be more complicated as West Germany did not have its own uranium resources. AEG had assured IVO that fuel could be purchased through the Atoms for Peace project, but this was known to be impossible because Germany was also committed to Euratom (e.g. Laurila, 1967, pp. 258–259). Meanwhile, the US and USSR provided conflicting information as to whether they would agree to sell the fuel should the reactor be purchased from someone else (e.g. Michelsen & Särkikoski, 2005, p. 85).

The call for tenders was reversed when the Soviet bid arrived in the spring of 1966. The USSR had been called to give a bid, half believing they would not have the technology,[68] but they replied with more than a tender. In fact, the Soviets understood the entire agreement as an intergovernmental one, not between companies; thus, they sidestepped IVO and instead directly with President Urho Kekkonen and the Finnish government (Michelsen & Särkikoski, 2005, pp. 80–81; Särkikoski, 2011, p. 220).

Trade negotiations between the USSR and Finland were generally given high political priority, and the USSR clearly wanted to link nuclear power to the same bilateral system. In general, Soviet trade accounted for about one-fifth of Finland's foreign trade. In practice, Finland imported crude oil and exported industrial products to the USSR. With regard to trade, the more Finland imported from the USSR, the more the USSR ordered goods from Finland. However, Finland imported low-value-added products, which did not please the USSR (e.g. Pihkala, 2001). In addition to these factors, it is worth remembering the realities of superpower politics. Trade was one avenue the Soviet Union used to bind Finland to itself economically (e.g. Kuisma, 1997). Moreover, on a larger scale, the Soviet Union sought to export nuclear power plants. The USSR, therefore, wanted a portfolio project that could advertise its *Vodo-Vodyanoi Energetichesky Reaktors* or Water-Water Energetic Reactors (VVERs) to subsequent buyer candidates (Schmid, 2011; 2015). Addressing a bid directly to the Finnish government was certain to pressurise the politicians and politicise the procurement process (e.g. Säynässalo, 2009; Sunell, 2003).

Since the views of the Finnish government did not coincide with IVO's, the bidding led to a deadlock. IVO would have liked to buy a Western reactor – preferably from Germany – but foreign policy was a clear priority, and buying from Germany would have been catastrophic. At that time, the issue of the two Germanies and the diplomatic relations to be had with each was one of the most difficult issues in Finnish political history. However, IVO's corporate management was not as concerned about the political implications (Vuorinen, 2015). The Finnish government, therefore, decided to postpone the procurement case until IVO's General Meeting, where the government could vote – as the IVO's majority shareholder – to abandon the project. As PM Mauno Koivisto asked, clearly indicating that the state had exercised its power as the entity which should be setting the rules, 'does the tail wave the cat or the cat wave the tail?'[69] The government had effectively decided that the nuclear procurement process was over, and IVO was ordered to build a non-nuclear power station instead.

Nuclear negotiations resumed after a short break, however; this time, the British option (UKAEA) was seen as the strongest (Särkikoski, 2011). Simultaneously, the USSR improved its offer, especially in economic terms (Schmid, 2015, pp. 108–110; Wealer et al., 2018, p. 141). The British technology would have enabled the production of plutonium, which would have endangered the non-proliferation argument repeated by the Finns, and the problem of nuclear fuel supply remained. Therefore, the Finnish government eventually concluded an agreement with the USSR in the spring of 1969, and the government began negotiations with the Soviets about purchasing a nuclear power station. The choice had been made, and in a way, the 'network' (Donzé & Nishimura, 2014) was actually the strongest contributing factor in the technology transfer. From here on, technology dissemination and adaptation to local circumstances were the most important factors.

Despite Soviet standardisation and various improvements in their technology, IVO was now being forced to order a high-tech/high-risk product, and it had no choice with regard to the technology. Moreover, IVO did not get the turnkey delivery it had wanted; thus, it would have to assume joint responsibility for the progress of the project with the *Atomenergoexport* supplier. The positive side of Soviet technology was that it had already been tested and was being used in the USSR. The VVER actually cost less to operate as it was more efficient than competing technology, but refuelling was a major downside; it needed to be undertaken while the plant was shut down (Schmid, 2015, pp. 108–110)[70].

The biggest differences lay in safety culture and regulations (according to the investigations of the Finnish Atomic Energy Committee). In the USSR, reactors were located in peripheral regions, and given their large number, the failure of one reactor would not have a large negative effect on the entire network load. In Finland, however, the reactor would be close to population centres, and a single reactor would account for a major share of electricity production[71]. For this reason, Finns had to order and partly re-plan for structures conforming to safety standards in the West (such as tighter cladding) and other safety features modelled along the lines of the Westinghouse solution. These details were, however, carried out by a Finnish company, Wärtsilä, a rapidly growing private enterprise that was nevertheless close to the state due to having been employed in the war reparations programme. In addition, the Finns bought an American state-of-the-art emergency condenser system from Westinghouse and instrumentation from Siemens. Ready computer control systems with training and simulation programs were provided by the Finnish company Nokia (Michelsen, 2007, pp. 14–16; Michelsen & Särkikoski, 2005; Ranta, 1993, pp. 414–418, 421).

The Soviet Union was surprisingly positive about the changes demanded by the Finns. As was customary in these kinds of ventures, Finnish specialists also visited Novo-Voronezh for training, just as another Finnish delegation of high-ranking civil servants, scholars and representatives of business fields had done 3 years earlier in 1966 (Poutanen, 2014, pp. 40–42). The construction of a modified 440 MW Russian Pressurised Water Reactor (VVER model p. 213) for Loviisa, located on the south coast of Finland, thus began in 1970, and the reactor was eventually handed over in May 1977. The contract for a second unit was then drawn up in August 1971, and the plant was ready in January 1981.[72]

The Soviet agreement solved the fuel problem for IVO's VVER reactors. The agreement included both the supply of fuel (at the same price as that offered by the US) and the recycling of the spent fuel for free by the Soviet Union (Aalto et al. 2017).[73] Various considerably different alternatives had been explored with regard to the fuel issue. For example, Sweden's *Allmänna Svenska Elektriska Aktiebolaget* (ASEA) promised to supply the technology needed to produce the fuel elements, while the Canadians promised to actually build a fuel element factory in Finland (Michelsen & Särkikoski, 2005, p. 85). Erkki Laurila (1982, p. 162), chair of the Atomic Energy Committee, however, thought the idea of a full service was far more sensible than procuring fuel separately, in which case subsequent processing would have to be arranged domestically.

Nuclear energy construction got underway in the early 1970s, and the Finnish Advisory Board on Energy Policy (1972, 1976) was in favour of a rapid build-up. Although a power station tied up a considerable amount of capital up front, the enriched uranium would be comparatively cheap and relatively little would be needed, which made it highly advantageous in terms of fuel storage, security of supply and balance of trade (Advisory Board on Energy Policy, 1973, pp. 38–39; Advisory Board on Energy Policy, 1976, pp. 49–50). The public debate highlighted the fact that cheap energy was essential for economic growth. Not only did it contribute to heavy industry, but it also allowed for the modernisation of agriculture and the textile industry.[74]

Subsequently, the construction of up to eight reactors was planned.[75] These matters were considered at the highest political level.[76] Under pressure from the USSR in 1969, the Finnish political elite decided that IVO would order the first power station from the USSR, while a privately owned company, *Teollisuuden Voima* (TVO[77]), would be allowed to order the next from elsewhere. In practice, due to political factors excluding West Germany and Britain, only the Swedish ASEA remained an option (Särkikoski, 2011, p. 284, p. 433). Even then, the issue became politicised and personified to the highest level, as the President Kekkonen had good relations with both the Swedish industrialist Marcus Wallenberg and the USSR (e.g. Koroma, 2015, p. 307).

When TVO's 'Olkiluoto' Project began, it was underpinned by private industries that wanted to build a cost-effective source of energy following the 'Mankala model', which meant that the owners would be able to buy electricity at the cost of production. TVO ordered two 660 MW BWRs from ASEA Atom in Sweden (e.g. Ranta, 1993, pp. 415, 418). According to TVO's Chairman Westerlund (Vesikansa, 2004, p. 170), the size of the power station was chosen to be outside the range known to be available as per the USSR's capability. Thus, the invitation to tender was sent to the USSR with the firm knowledge that they would not be able to make an offer (see Häikiö, 2001, pp. 132–134).

TVO's units were completed in the years 1978 and 1980. However, buying uranium in the mid-1970s from the free market was still not possible. ASEA had promised to supply the fuel, but the Finns wanted to avoid being too dependent on ASEA. Thus, the fuel was bought from Canada, transported to the USSR for enrichment and then taken to Sweden, where the fuel elements were made (Valkeapää, 2016, p. 33). Although TVO's history considers the solution to be economically sensible (as TVO was able to purchase its raw materials on the market), it is clear that enrichment had to take place in the Soviet Union for political reasons. Even for this solution, the Soviet Union had to be persuaded by promising that the IVO would continue to buy its reactors from the East. In these negotiations, the Finns invoked to the Soviet Union's notion of the 'peaceful coexistence of peoples' and apparently suggested that the next IVO nuclear power stations would be ordered from the USSR (e.g., Koroma, 2015, p. 307; Vesikansa, 2004, pp. 171–178, p. 183).

After the 1970s, however, the political tide started to turn against nuclear power. In the 1950s and 1960s, Parliament had not been particularly active in covering nuclear matters, but there was a positive consensus about its affordability. The high tide of nuclear power happened at around the same time as the oil crisis (1973), but with the slowdown in economic growth and the transformation of industrial structures (Sänkiaho & Rantala, 1987), the tide was already ebbing. Public opinion about nuclear power was hit, first tentatively, by the Harrisburg accident in 1979 and, then decisively, by Chernobyl in April 1986, at which point plans for further construction were shelved. IVO's plans to purchase the 1000 MW power station from the USSR never materialised, and in fact, no nuclear power station appeared there until the early 1990s. Equally slow in coming was the decision to build Finland's fifth nuclear power station, 'Olkiluoto 3' (EPR), which was not made until 2002 (Wealer et al., 2018, pp. 80–81, p. 142). In the fall of 2020, the project was still in progress due to numerous setbacks.

Comparing the centre and the periphery

We have presented three somewhat simplified cases of atomic development, which illustrate the spread of atomic technology from the centre towards the periphery and the commercial development of its civilian uses. Table 1 displays the main features of each case with regard to its technology, policy, politics, and fuel type. The comparison reveals that the closer the relationship between the state and the political centre and the better the connection between the centre and the periphery, the easier and more feasible the technology transfer. This corresponds to theories which suggest that transfer speed and flow increase the closer one gets to the centre. However, for security and foreign policy reasons (due to the political sensitivity of atomic power), the technology transfer was regulated by the availability and supply of required raw materials as much as the technology itself. This meant that the politics surrounding the control of this fuel affected the gradual spread of technology.

All of the cases presented in this article show signs of political path dependency, where one trajectory involved heavy investment at the cost of other potential options, which then made changing course extremely difficult. The decisions made in the initial phase of the 'atomic age' delayed the development of atomic technology for civilian uses by at least 9 years. These decisions related to Anglo-American attempts at establishing an atomic oligopoly at first, followed by a monopoly for the US. During these years, the major atomic powers could not agree on suitable regulatory measures that would enable the legitimate dissemination and transfer of atomic information and technology. Co-operation was forbidden, and competitive national interests prevailed. The availability of raw materials was a contentious issue at the outset, as the major atomic powers reinforced their individual or joint privileges over the various known fissionable raw materials. These three cases show, above all, how atomic energy could not escape the clutches of Cold War politics and bloc alignments.

The British case is different from our other examples as well as the other national histories of civil development covered by, for instance, Puig (2008, 2011). Britain was actually at (or close to) the centre initially, and along with the US and Canada, it had considerable advantage over other states; yet it did not become a leading state in commercial atomic development. However, despite the British attempts and considerations, they were soon shifted to a more outer rim – a periphery, if you may. From the viewpoint of networking, what appeared to be a strong connection and collaboration crumbled rapidly due to national interests. Though the initial project of the British had been science-driven, the military and political establishments soon got involved. Britain thereafter focused first and foremost on an atomic weapon project, and in this respect, it can be considered as a kind of an outlier. Despite their initial

Table 1. Summary of the main features of each case discussed in this article.

Main features	Britain	West Germany	Finland
Initial goals	-acquiring atomic weapons -strategy and prestige -technology consolidation -energy crisis -civilian uses less important	-cheap energy for growing industry -hyperbole -technology transfer -some prestige -later on business from nuclear technology business	-cheap energy for growing (export) industry -hyperbole and availability -technology transfer -some prestige -limited resources for energy
Main operatives	Initially science driven, -then government-military-mix -outsourcing mainly in construction -increased role of business only later	Government-Industry mix	Government-Industry-Science mix
Centre-Periphery position and Alignment W/E-axis	Almost centre, -Breakdown of cooperation in 1946 -Ally; West -'special relationship to US'; NATO	-semiperiphery -Former enemy, -Marshall Aid -> West; NATO 1955 -> ally	-periphery -Former enemy; -Non-aligned; de facto East
Main affecting regulatory transition/ instruments?	-war and safety -high costs of research and design, gaseous diffusion especially -CDT-arrangement and raw material supply focus to US, -US 'atomic diplomacy' -End of Anglo-American atomic collaboration, -UN control commission plans failing, -McMahon Act and US Atomic Energy Law 1946 -raw material oligopoly and competition within 'the west'	-Previous regulatory attempts and resource regulation -IAEA, Atoms for Peace, Euratom etc. -British-US 1955 Agreement -new technology for enrichment (centrifuges) emerging Peace treaties, NATO-treaty	Atoms for Peace. Finno-Soviet Treaty of 1948; Paris Peace Accords; IAEA etc.
Raw materials used for 'fuel'	Nat. U. U-235, U-233/238, Plutonium, thorium abandoned more or less (CDT/CDA dependency) Commonwealth produce, secret arrangements	Nat. U. U-235, U-233/238, Plutonium, thorium implemented at experimental level, closed cycles etc. dependency on import, yet desire on more independency, all uranium now imported, heavy public resistance of reprocessing	Nat. U. U-233/238; USSR provides fuel, takes care of the nuclear waste, dependency on USSR fuel. No enrichening plants.
Technology origins	US-GBR / GBR since 1946, civilian 1955->	First research reactor with the US assistance, light water reactor	USSR
Offers requested/ received?	In 1946 none, independent project	US	US, USSR, later W-Germany, and Sweden
First reactor types/ origins?	GLEEP	SWR	VVER-PWR
Projects initiated	1939/1946/1954–1955	1954–1955	1950s
Energy production of the first plants?	Calder Hall	Versuchsatomkraftwerk Kahl (experimental: Rheinsberg 1966; Obrigheim)	Loviisa-1
Parliamentary aspects?	Hyperbole, -> defence -> for. Pol. -> domestic and civilian uses, - heavy government curbing attempts on the matter, also used as diplomatic weapon against the US	Hyperbole -> energy for industry, - non-weapon emphasis, environmental aspects	Limited initial interest in Parliament government-business relations more important
Turnkey subscribed?	No, not possible	No	Yes
Relation to Atoms for Peace?	No	Yes	Yes

role in the original national project, the roles of companies such as ICI eventually proved to be quite limited. Most private companies worked as subcontractors or agencies. The private sector, even if it was closely tied to the state, did not see the Atoms for Peace project as a feasible or promising venture, as it demanded too much and gave too little compared to other opportunities.

The advantages the British were to gain from the new technology were uncertain as the only application it had been used for up to that point had been the atomic bomb, but perhaps, in strategic terms, it was thought that atomic technology might confer some prestige. Commercial applications were seen to lie in the future, however vague they appeared at the time. The emphasis on weapons made them harder to follow, and in any case, the Americans had received the rights for civilian and commercial uses as part of the Quebec agreement. The limited availability of the raw materials that remained after the CDT agreement folded translated into a limited supply of unrefined ore and an even more limited supply of enriched material. This contributed to the abandonment of the thorium option and the adoption of a plutonium-oriented approach instead, as developing a British nuclear weapon was the priority. The upshot of this was that plutonium was less suitable for commercial uses and required higher technological capacity than the British had at the time. With regard to commercial use, the limited supply of fuel meant that Britain eventually chose a technology that ran on natural uranium. The British case also highlights how Parliament and the executive were drifting apart. Parliament increasingly wanted to know more about possible civilian uses, international co-operation, and regulation of the new technology. In fact, the government's policy may have delayed commercial development. It was hoped that domestic political pressure could force the Americans to comply, but instead, it contributed negatively to policy execution to some extent. British efforts were clearly hampered by their 'special relationship', which was increasingly turning out to mean general dependency on the US.

The West German case is a more typical example of new technology spreading transnationally from the centre towards the periphery. Initially, Germany had even strived to establish a base as the centre, but it lost that position due to the World War II-related developments. Despite this difficult situation, including the very limited availability of raw materials, West Germany established strong networks (in no small amount due to its political situation) with the US. From the viewpoint of the centre-periphery argument, the Germans were extremely capable of drawing upon the benefits of the established networks. High engineering skills and capabilities were just two of the contributing elements. However, despite some network connections, due to political issues and the lack of an indigenous resource supply, Western Germany was initially a precarious partner for nuclear technology transfer (at least for some). The Finnish case testifies to this and furthermore emphasises the role of political networks and alignments. Co-operation with Germany was lucrative and would have suited the Finns due to numerous reasons, but due to political grounds, it was not possible. Same applied to the hypothetical co-operation between the Soviets and most Western states.

West Germany clearly benefited from the Atoms for Peace initiative, and aimed – not least for political and historical reasons – to develop civilian uses for atomic technology. The project only started after the Atoms for Peace and Euratom regulatory bodies were established. The Germans prioritised providing electricity for their growing economy, and this aspect was encouraged by the American Cold War policy to create an economic drive in Europe (note that it could have also acted as a source of resilience against the competing Eastern bloc). As the West German project abstained from weapons feasibility and Germany was under the nuclear umbrella of NATO and the US, it chose LWRs and decided to research different technologies, ultimately contributing to its becoming a world class competitor with the US. However, resource self-sufficiency was a priority question that the Germans could not avoid either. They were dependent on fissile fuel that the Atoms for Peace project, as a regulatory policy, offered at a low price. In this manner, the European attempt to devise new enrichment processes was effectively derailed by the US and postponed for a while.

However, the technological research eventually paid off as more self-sufficient technology was developed. Unlike Finland, West Germany was politically much closer to the US than many other states, and it had transformed itself from a former enemy into a worthy ally that deserved support in providing nuclear power to drive its economic growth forward.

Finland was on the very edge of the political periphery by comparison (without actually being a member of the Eastern bloc). As a former enemy of *both* the major suppliers of civilian atomic technology and resources, its position was, therefore, rather different. Finland attempted to pursue the kind of technological transfer that would typically be considered 'free'. In reality, the now more established networks were heavily in play once again. Finnish diplomatic expertise proved to be crucial in playing these networks.

Finnish industry was growing rapidly during the 1950s, and the chemicals and paper and pulp industries especially required a plentiful and affordable source of energy.[78] A small circle of Finnish atomic enthusiasts believed that technology transfer would have positive effects, and thus, the initial Finnish project was industry-driven and private. However, the government intervened as there were important political aspects to consider.

Originally, the Finns had only wanted turnkey atomic power for civilian use but then had to learn the technology too. Based on the sources available to us, the Finns understood most of the project-related political entanglements that might arise. The whole process of diffusing civilian nuclear technology to the Finnish periphery reveals that the Finns tried to avoid these entanglements as much as possible. This is why they oriented towards the CANDU (Canadian Deuterium Uranium Reactor) and German projects. However, powerful exogenous factors, namely interventions and pressure related to foreign politics, pushed the Finns towards a kind of lock-in type of alignment with Soviet technology. The Finns were, however, able to develop domestic knowledge and integrate Western technology with their Eastern acquisition. These are clear signs of more or less successful attempts to break the path dependency. In this game, fuel was not the only (nor even the most important) factor, but its role was much greater than has generally been considered before. It was the game changer the major atomic powers had used to their own ends to achieve favourable political alignments suited to their respective spheres of interest and to regulate the use of the new technology.

'Being late' and being on the periphery had its benefits – the technology was available, and it had also been tested. The fuel supply and market situation had, in the meantime, improved marginally. Choosing technology meant alignment with a technology provider. Availability of the right fissile material to operate that technology (in the form of a nuclear power station) also required this alignment. Given its geopolitically precarious position between the East and the West, Finland had to consider her options seriously. As the American supply of raw materials might have been limited, due to great international interest in the Atoms for Peace Project and allies being served first, Finland could not simply order technology from the West, even if it was more reliable and advanced. For political reasons, it was not possible to order technology from one Cold War bloc and raw materials from the other. The Americans were worried about industrial espionage by the Soviets and stated they would only deliver technology with the provision of fuel arrangement included. They would not provide fuel for Soviet-built technology either. Thus, Finland had to revise her plans, and as the Soviets offered a lucrative package deal, which included the disposal of nuclear waste, they opted for the geopolitically safe option of maintaining a neutral image (especially towards the USSR). By this time, the technology had developed to a point where turnkey orders were also available.

Conclusions

We started this article by referring to a simple and archetypical centre-periphery framework of technology transfer. However, charting out the heuristic and geospatial progress, to which this approach is very suitable, has shed light on the complexity of the issue. Although the simplified centre-periphery approach was hypothetically fruitful and allowed us to include political elements in this equation, the gradual historical development of networks and rising complexity of the matter soon became evident as increasingly imperative factors. The fuel for the nuclear 'fires', namely the availability of fissile materials for civilian use, was one of the most important factors. Moreover, it was one of the defining elements the great powers utilised in their respective nuclear policies. Therefore, this article suggests that the development of atomic technology depended to a great extent on the raw material supply in each context. The availability of any raw material being crucial for technology and innovation adaptation is not a novelty *per se*. However, given that it is an explicit demonstration about one crucial angle, it represents a potential means to approach the transnational character of technology transfer as presented, for instance, by Puig (2011).

We have shown that the availability of raw materials and fuel for atomic research and development, and that of technology for developing civilian uses of atomic technology were first intrinsically tied to the military application of atomic energy. Thus, nuclear fuel became very closely connected to the politics, allegiances, and competition among the major atomic powers, developing from the centre to the periphery as time wore on. The players in each national case naturally had their distinctive features to consider, but they all faced the same essential question: where would they get their raw materials from? We argued that in the context of civilian development of nuclear technology and its transfer, a politically motivated vendor lock-in was a clear risk. The piecemeal diffusion of civilian nuclear technology can thus be partly explained by dependency on the supply of particular nuclear fuels. The availability and security of this fuel supply appear to have determined not only the type of technology available but also who it was sourced from and all the political implications that this entailed.

As regards the availability of raw materials and the politics behind it, the decade between 1945 and 1953–1955 seems to have been instrumental in creating the practices and framework that would determine the availability of atomic technology and raw materials throughout the Cold War years. The attempt to create an Anglo-American oligopoly of atomic power fired up a competition about the raw materials, and so began the arms race. As the attempt to regulate the new technology via the UN also failed, controlling and refining the raw materials became even more important. Even after 1953–1955, when the Atoms for Peace initiative signalled the start of a 'golden era' for developing the civilian uses of atomic technology, the state control exerted over nuclear raw materials ensured that nuclear technology for both civilian and military purposes developed only gradually. Indeed, the role of state-owned companies remained important throughout the post-war period, and despite establishing a certain framework for grants, research, and design, the private business sector was kept in check by the respective interests of each state. The private sector also depended on the state more than may have previously been thought – especially in the case of IVO in Finland. A state-driven approach in development was therefore the norm due to the aforementioned political entanglements. In general, the role of private companies in the development of nuclear technology only increased later, as other frameworks became established. The precise nature of these frameworks of private business and their exact effects on state politics remain to be studied in closer detail.

Notes

1. We agree that even Manhattan project and Tube Alloys-project, and the joint Anglo-American-Canadian project were more complex, too. The variety of actors, interests and networks was evident in the development of the atomic weapons. However, it was only later on, and in part due to political decisions made, such as the plans for international atomic regulation under the auspices of the United Nations, that the atomic question grew too wide to be regulated on the basis of the Anglo-American-Canadian interests. For instance, the idea of regulating diffusion of the new technology through the means of controlling fissile materials lasted longer.
2. Studies on the economic as well as environmental history have been somewhat limited (e.g. Kaarkoski, 2016) although those on nuclear waste management and nuclear moratoria have become more common (Bergmans et al., 2012, 2015; Lehtonen, 2010). The works of Rubio and De la Torre (2017, 2015) and De La Torre (De La Torre & García-Zúñiga, 2014; De La Torre & Rubio, 2015) are important exceptions, as they take into account the political aspects of Spain's nuclear power policy and economic history to some extent.
3. Exceptions include Helmreich's works (1986, 1998) and Hecht (2012).
4. Hughes (1993, pp. 285–323) saw war as a great mobiliser in history, given its ability to bring together the private and state sectors, and to create the kinds of networks that might otherwise be difficult to establish without heavy external pressure and exceptional circumstances. Such coming-together-of-forces also occurred during World War I in the electricity business. To learn about the effect it had on the electricity business, see Wengeroth (2000).
5. This could also be considered more simply as jealously guarding and regulating strategic resources due to the need to achieve a positional advantage in relation to others by beggaring thy neighbour.
6. Henry de Wolf Smyth's official report on the (American) atomic project's history was supplemented with information about British contributions. This report was based on the British Government's White Paper on Tube Alloys after it had become part of the American project.
7. See Wilson (1995, pp. 172–173). See also Reader (1975).
8. Detailed research on the role of ICI during the wartime and post-war atomic projects has not been conducted. This aspect has been briefly touched upon in Reader's (1975) two-volume company history and some subsequent works. The lack of information can be attributed to the archival series of the TNA AB 16/819 Imperial Chemical Industries Ltd. records, which covers the years 1949–1952, remaining classified despite the Waldegrave Initiative of 1991 (the review for declassification is ongoing). In Finland, the use of the IVO (*Imatran Voima*) records depends on the approval of the current mother company (Fortum), according to information obtained from an exchange of emails with ELKA Archives and the public liaison offices of Fortum.
9. TNA FO 800/552, Memo by N. Butler for Mr. Ronald, 30 August 1945. HC Deb, 16 August 1945, vol. 413 cc. 78–81. HC Deb, 21 August 1945, vol. 413 cc. 441–444. Both the opposition and government were equally eager. Requests for information, other questions, statement demands and suggestions for policy have been covered in detail only by Roitto (2015, 2016).
10. TNA CAB 134/7 ACAE (45)7, Churchill's statement, read by Attlee on 6 August 1945.

11. No. 192 (Undated), Memorandum by Mr. Attlee on the Atomic Bomb (slightly revised and circulated as GEN 75/1 on 28 August 1945), No. 189, Bevin to Balfour (17 August 1945), DBPO, series I, vol. II. '…it is difficult to draw a line between developments for defence purposes and those of commercial application…'.
12. TNA CAB 134/7, ACAE (45)5, Co-operation Between the US and UK Governments, note by the Secretary. TNA CAB 134/7, ACAE (45)9, 11 September 1945, Past History and Organisation of the Work, a note by the Secretary. TNA CAB 134/7, ACAE (45)2, Future Policy and Programme of Research in the United Kingdom, 24 August 1945, including a memo 'Tube Alloys Future Policy and Programme' by Sir John Anderson (then Chancellor of the Exchequer).
13. HC Deb, 29 January 1946 vol 418cc. 682–683. PM Attlee's answer about the future of British atomic research.
14. The US publicly declared that the Manhattan Project cost around $2 billion (1945) and that the project had employed 125,000 people at its peak. Atomic Bomb, Truman Press Release, 6 August 1945.
15. No. 186, A Memorandum by Campbell to Bevin, 8 August 1945, DBPO ser. I, vol. II. see Gowing (1974, p. 7).
16. 'Let Us Face the Future': A Declaration of Labour Policy for the Consideration of the Nation. Labour Party Election Manifesto 1945.
17. Groves–Anderson Memorandum, Washington, 16 November 1945. Printed in No. 240, Memorandum of Conversations in Washington, 16 November 1945, CAB 130/8, circulated also in the Cabinet Office on 12 December 1945 as GEN 106/2 (footnote 1, Bullen 1985, p. 628), DBPO ser. I, vol. II.
18. Ibid.
19. TNA FO 800/438, Telegram from Foreign Office to Washington, 27 November 1945.
20. TNA FO 800/547, Advisory Committee on Atomic Energy, Sir J. Anderson's Proposal for an Experimental Establishment. HC Deb, 29 October 1945, vol. 415, cc. 38–39.
21. The 'statement' was actually a planted question; see. TNA CAB 104, note by E. Bridges for Prime Minister Attlee, 24 October 1945.
22. TNA FO 800/552, Perrin to Toynbee, 31 October 1945.
23. HC Deb, 7 November 1945, vol. 415, cc. 1312–1317 (Col. Lindsay; Solihull, Lab).
24. TNA FO 800/585, GEN 75/23, Large-scale Production, 16 January 1946. GEN 75/24, Large-scale Production, note by the Prime Minister, 23 January 1946.
25. TNA CAB 134/7, ACAE (45)1, 20 August 1945, Cabinet Advisory Committee on Atomic Energy, Terms of Reference, note by the Secretary of the Cabinet (E. Bridges).
26. TNA CAB 134/7, ACAE (45)5. Co-operation Between the US and UK Governments, note by the Secretary. TNA CAB 134/7, ACAE (45)9, 11 September 1945. Past History and Organisation of the Work, note by the Secretary. TNA CAB 134/7, ACAE (45)2, Future Policy and Programme of Research in the United Kingdom, 24 August 1945, including a memo 'Tube Alloys Future Policy and Programme' by Sir John Anderson (then Chancellor of the Exchequer). TNA FO 800/547, Butler to Cadogan, 1 November 1945 (intended possibly for GEN 75 meeting: 'I submit the revised official's report for consideration at this evening's meeting of Ministers…) about the control plans. The United States would require a quid pro quo approach, the USSR would benefit from having guarantees against surprise atomic attack, and the Americans would like to have raw-material monopoly'. No. 226, Minutes from Mr. Makins to Sir J. Anderson, Washington, 14 November 1945, CAB 126/276 DBPO, ser. I, vol. II.
27. TNA FO 800/438, Prime Minister's Personal Minutes, ser. M. 101/45, about limiting 'atomic questions' in general due to 'national interests', see TNA PREM 8/113.
28. TNA CAB 126/58–CAB126/64, which included several general folders about raw materials and reports by country.
29. HC Deb, 18 March 1946, vol. 420, c. 1499. This was a question about the uranium deposits in Travancore asked by Raymond Blackburn. The question alarmed the British officials due to potential security leak about secret raw material arrangements. Blackburn also asked whether Britain intended to deliver thorium finds under the United Nations' control. HC Deb, 20 May 1946, vol. 423, cc. 23–24.

30. HC Deb 17 August 1945 vol. 413 cc. 262–263.
31. The roles of private interests or companies were very limited as per the 6000 document pages collected from the TNA for research purposes. Granted that these documents are not directly related to the companies and businesses, but as it was well-known that these matters were considered within the inner circle of Attlee's cabinet and that technical bodies played limited roles, the absence of mentions of businesses in the primary sources is an important indication. Regarding the inner circle, see Bullock (1984), Gowing (1974), Hennessy (2001), Morgan (1984), and Roitto (2015).
32. TNA FO 800/549 ACAE (45) 61, Cabinet Advisory Committee on Atomic Energy: Cooperation Between the United States, Canada and the United Kingdom, note by joint secretaries (Rickett and Clarke) covering draft instructions to Washington, 8 December 1945.
33. TNA FO 800/585, GEN 75/25, Cooperation Between the US UK and Canadian Governments, note by the Secretary of the Cabinet (E. Bridges), 11 February 1946. Annex I.
34. TNA FO 800/552, Robinson to Foreign Office, 21 December 1945.
35. TNA FO 800/438, Telegram from Field Marshall Smuts to Attlee, 21 December 1945.
36. TNA FO 800/549 ACAE (45), 9th meeting, 5 December 1945, Draft Minutes of a Meeting of the Committee Held on Tuesday 4 December 1945, including minutes about the atomic files and classification.
37. Other secret arrangements, such as one between Stalin and Roosevelt about the Kurile Islands, had been leaked, causing public outcry in the US and adding to the rather convenient pressure against secret arrangements. See TNA FO 800/527, ANCAM 528, Makins to Rickett, 4 February 1946.
38. TNA FO 800/527, Rickett to Butler, 28 February 1946; ANCAM 548 from Chadwick to Rickett, 6 March 1946; ANCAM 558 from JSM to Foreign Office, 16 March 1946.
39. TNA FO 800/438, Bevin's minutes to PM (P. M. Paris/46/2).
40. TNA FO 800/527, Makins to Butler (REF: 24/-/46), 22 January 1946.
41. No. 34 Joint Staff Mission (Washington) to Cabinet Office (Received 17 February, 1.35 a.m.). ANCAM 536 Telegramic [U 3830/20/70], Washington, 17 February 1946, [U 3830/20/70], DBPO ser. I, vol. IV.
42. FO 800/438, Telegram from Foreign Office to Washington, 23 April 1946.
43. Calendar notes ii, ANCAM 585 (Butler's memo) and ANCAM 597, DBPO, ser. I, vol. IV.
44. FO 800/438, N. Butler's letter to Sir O. Sargent, 22 November 1946.
45. No. 89 Cabinet to Joint Staff Mission, 4 May 1946 (CANAM 581) DBPO, ser. I, vol. IV.; see Roitto (2015, pp. 347–355).
46. TNA FO 800/528, Minutes from North American Department, 17 April 1946.
47. No. 86 Joint Staff Mission (Washington) to Cabinet Office (Received 3 May, 12.8 a.m.). ANCAM 603 Telegraphic [U 4849/20/70], Washington, 2 May 1946, [U 4849/20/70], DBPO, ser. I, vol. IV.
48. TNA FO 800/438, Prime Minister's Personal Telegram, Sr. No. T.326/46, Attlee to Truman.
49. TNA FO 800/585, Note of GEN 75/12th meeting on 20 March 1946.
50. TNA FO 800/438, Bevin's Minutes to the PM, 10 July 1946. TNA FO 800/438, Bevin's Minutes to the PM, 46 P. M./46/133, 6 August 1946. TNA FO 800/585, Note of GEN 75/12th meeting on 20 March 1946.
51. TNA CAB 134/7 ACAE (45) 3, Advisory Committee on Atomic Energy. International Policy on the Use of Atomic Energy. Note by the Secretary (Rickett), 24 August 1945, including a memorandum dated 7 June 1945 by an unnamed group of officials, signed by the Office of the Cabinet.
52. FO 800/438, N. Butler to R. Stevens, 22 July 1946.
53. FO 800/528 CANAM 639, 14 September 1946.
54. The CDA was a modified version of the CDT.
55. The US pushed through a motion in the CDA that meant allocating all of the ore gathered from the Belgian Congo in 1948–1949 for the US. US-dependent Britain could not also resist further demands. According to the Modus Vivendi, which was very much in effect, should the US have required more ore than the Congo would have been able to provide, Canada and the UK would have had to deliver ore from their respective unprocessed emergency reserves (Gowing, 1974).

56. No. 64, The Chancellor of the Federal Republic of Germany to the Secretary of State, 27 May 1952; Conference files, Lot 59 D 95, CF 108 No. 43 Minutes of the Meeting of the Foreign Ministers of the United States, the United Kingdom, and France, 24 May 1952, 2:30 p.m. FRUS Vol. VII, Part 1.
57. Shippingport Atomic Power Station, HAER No. PA-81.
58. See e.g., Deutscher Bundestag, 194. Sitting, 22 February 1957, 11052–11053.
59. Deutscher Bundestag, 14 December 1956, Drs. 2/3026; Deutscher Bundestag, 194. Sitting, 22 February 1957.
60. Hochtemperatur-Reaktorbau GmbH, Mannheim (FRG).
61. The technology of enriching uranium could also have been used to make weapons-grade HEU material, but this would have no doubt posed a strategic and political risk for Finland's neutral position. The same applied to Plutonium which was considered as a valuable side-product for a while when ideas about the potential technologies to select were being entertained.
62. However, the legislation restricted the activities of foreign companies in Finland.
63. The founding companies were Kajaani Oy, Kemi Oy, Oulu Oy, Rauma-Repola Oy, and Veitsiluoto Oy. These could be described as some of the key players in the Finnish forest industry sector, which had interests in securing cheap energy production for their developing processes.
64. At the time, Sweden still had a nuclear weapons programme.
65. Erkki Laurila's letters in the Finnish National Archives (FNA), *Atomienergianeuvottelukunta*, Ha. 1.
66. Incorporating a by-products or weapons programme thus had a serious effect on the calculations even if their nature is more intangible. In 1945–1946, like the Americans, Britain had opted to establish independent, high-cost, non-profitable and resource-hungry programmes notwithstanding the cost. Such programmes also had severe political implications, given their high-risk/high-reward scenario. The case proves how deeply the political sphere was involved in the business and economic side of atomic energy – especially if we bear in mind that in the British case, the costs had remained hidden within the Ministry of Supply's budget (see Gowing, 1974, pp. 48–55).
67. For instance, geopolitics concerning the mining countries' stability and allegiances have played an important role in this regard. During the Cold War, 20–50% of the world's uranium was mined in the Congo, Nigeria, South Africa, Gabon, Madagascar and Namibia (Hecht, 2012, pp. 56–66). Neff and Jacoby (1980, 3-1–3-22) [sic!] underline, however, that for a very long time, the western search for resources was limited to states that were friendly towards NATO nuclear powers.
68. ELKA Archives, which contains the atomic and nuclear power-related papers of IVO, requires a research permit from the current owner Fortum.
69. This is a literal translation. The typical expression in English would refer to the tail wagging the dog or vice versa.
70. Given the close-knit ties of the Finnish industry with state-owned companies, private companies, various other stakeholders and the state, this was not necessarily a problem, as the majority of industrial maintenance operations (such as paper and pulp or metal-related industries) were highly regulated by detailed collective agreements. Moreover, the operations were carefully pre-planned to take place during national holidays (see. Laine et al., 2019; Wuokko et al., 2020).
71. The Atomic Energy Committee's papers in FNA.
72. The Finnish authorities wanted to control the quality of fuel at the manufacturing stage, but the USSR did not allow any supervisors into their factories. Thus, the Finnish authorities did not allow the reactor to be operated at full capacity. IVO, in turn, did not pay the final bill to the Soviet *Atomenergoexport*, because the reactor did not reach the agreed level of power production. The situation was resolved when an acceptable quality control system was developed in conjunction with the Soviet Chamber of Commerce, which granted the fuel a quality guarantee, and sample batches were examined in Finland (Michelsen & Särkikoski, 2005, p. 254; Vuorinen, 2015).
73. Spent fuel was not seen as an important or difficult issue because, on the contrary to the present, spent fuel was believed to have a market value in the future. The agreement included the return of the spent fuel to Russia. The agreement remained in force until 1996, when the Finnish Parliament decided to terminate it (Kojo, 2009, p. 163)

74. *Miksi Ydinvoimaa Suomeen*, YLE documentary film, 9 April 1975.
75. If the forecasts had come true, eight reactors would have covered about a quarter of Finland's electricity consumption in 1985. This would have translated into roughly 250 tonnes of uranium imported per year (Advisory Board on Energy Policy, 1973, pp. 22–23; Advisory Board on Energy Policy, 1976, pp. 49–50). In reality, Finland was producing 41% of its electricity by nuclear power in 1983 (compared to 18%, 17%, 13%, 48%, and 7% for the FRG, England, the USA, France and the USSR, respectively) (Ranta, 1993, p. 423).
76. R. Kurki, 3 May 1974, notes on the negotiations on energy co-operation between Finland and the Soviet Union, which took place in Helsinki in April 1974 (title translated from Finnish). Top secret documents 1974. Archive of President Urho Kekkonen, Orimattila, Finland.
77. TVO was founded in 1969 by 16 companies that had been members of Finland's first nuclear project. IVO became a minority shareholder (40%) in TVO in 1979.
78. The main bleaching agent produced and used in the chemicals and paper and pulp industries, respectively, was chlorine. This element was produced mainly by the energy-consuming electrolysis of sodium chloride. At the time, most of the paper and pulp companies had integrated chemical pulp units within their factories.

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