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The nuclear 'renaissance' and the geography of the uranium fuel cycle

Romain Garcier

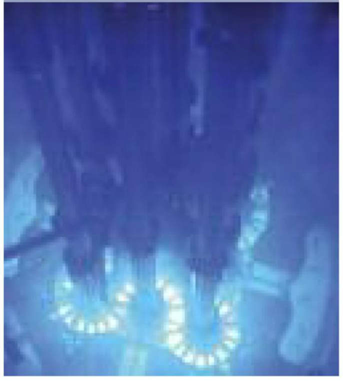
ABSTRACT: There is much talk in the media about the seeming inevitability of a 'renaissance' in the nuclear energy industry as a means of reducing carbon dioxide (CO_2) emissions. Less is reported, however, about the geography of the nuclear fuel cycle, and the various material constraints that affect the nuclear industry worldwide. This article addresses both these aspects of the nuclear energy industry, and considers the fundamental spatial and political mismatch between the places where uranium is mined, processed and consumed. It also considers how uranium has been culturally framed as a political object in the past, and the way in which this continues to have a bearing on its commercial circulation.

Introduction

Over the last 20 years, energy production has been growing at a staggering rate. The world economy currently produces about 12 billion oil equivalent tonnes of primary energy annually, a 30% increase over 1990 figures. The International Energy Agency (IEA) forecasts that by 2030 primary energy supply should have grown another 50%, driven by increasing energy consumption in the developing world – most notably India and China (IEA, 2008a, p. 46). Currently, more than 80% of primary energy supply comes from fossil fuels, the largest contributors to the atmospheric release of carbon dioxide (CO_2), and therefore to climate change. The world faces the considerable challenge of increasing energy generation while also reducing its contribution to climate change, calling in effect for the large-scale development of alternative, low-carbon energy sources (IEA, 2008b). Nuclear energy does not emit significant amounts of greenhouse gases, so the nuclear energy industry has hugely benefited from this new context.

Indeed, after 20 years or so in the wilderness following the accidents at Three-Mile Island (USA) in 1979 and Chernobyl (Ukraine) in 1986, the nuclear industry is buoyant. According to the World Nuclear Association, as of 2008, 30 new reactors were being built and 70 more were in an advanced state of planning, adding to the actual number of 440 existing reactors worldwide. Many countries have revised their nuclear strategy: for example, new reactors are being built in countries without a nuclear history (e.g. Iran), and some nuclear countries are recommitting to nuclear energy after considering a nuclear phase-out (e.g. Sweden and the UK). Nuclear energy is now presented by industry and governments as integral to sustainable, carbon-free development (UK DTI, 2007; UK BERR, 2008) and a rational and secure solution to the growing hunger for energy.

This narrative, however, misrepresents or neglects some fundamental aspects of nuclear electricity generation. First, nuclear energy accounts for about 6% of the energy produced worldwide (IEA, 2008a, p. 6). Even in France (which produces 78% of its electricity from nuclear sources) nuclear energy accounts for only 20% of total energy consumption, with fossil fuels covering most energy needs, including transport (DGEMP, 2008, p. 30). Doubling nuclear electricity production would only satisfy about 10% of the world's energy demand, and total 'decarbonisation' through nuclear energy would require the construction of between 20,000 and 30,000 plants. Nuclear power cannot be a substitute for fossil fuels but could play a role as a balancing element in energy mixes worldwide (Elliott, 2007).



Second, as well as traditional political opposition to nuclear electricity, there are numerous structural obstacles to the renaissance. If nuclear energy is to have any significant impact on CO_2 emissions, the rate of construction of new reactors will have to be increased spectacularly (NEA, 2008b, p. 14), putting pressure on the entire nuclear supply chain. Many new plants and upgrades to the existing obsolescent production and transformation facilities will be needed to fulfil a growing demand for natural uranium. Many more trade links and flows will have to be established and sustained to ensure the geographical expansion of nuclear electricity generation worldwide. This means that energy policy analysis cannot ignore the structural factors that constrain energy production. Strong energy provision choices made by governments are not enough to ensure the sustainability of the nuclear renaissance: the organisation of the nuclear fuel supply chain itself conditions such a large-scale redevelopment.

In this article, the geographies of the uranium fuel cycle are analysed, beginning with consideration of uranium, whch provides an interesting entry point into a geography of industrial commodities because it is saturated with competing meanings: uranium is, at the same time, a mineral resource, an energetic material, a dangerous element, a strategic asset, and the means of regional development, etc. In the corporate and institutional literature, however, uranium mining and transformation are generally presented in statistical tables, with little consideration for those aspects that frame and constrain supply, demand and commodity flows, namely historical legacy, technical hurdles to exploitation, unforeseen events and uncertainties, legal frameworks, and political interventions. By unpacking the geographies of the fuel cycle, this article shows that these factors have a significant bearing on the production and circulation of uranium itself, and act as structural constraints on the nuclear renaissance.

The article is organised as follows. First, it considers the influence of contextual elements on the legacy of uranium exploitation as an energetic material. Second, it introduces the notion of a 'fuel cycle' and analyses its geographical dimension. Finally, some problems are identified that are relevant to nuclear flows and are directly linked to the cultural framing of uranium and nuclear materials.

Uranium: the renaissance of an energetic material

Unlike fossil fuels, which have for centuries been used to generate power, uranium has only been used since the middle of the twentieth century. Military uses predominated up to the late 1960s since the production of atomic bombs requires **fissile** materials – uranium, or its derivative, plutonium. At that time, uranium supply was a highly sensitive issue and the industrial facilities needed for transforming uranium were developed on a national basis, often within the military itself. Uranium was seen as a very different energetic material from coal and oil, and this view of it has shaped the industrial fabric needed to supply and transform uranium to this day, even after civilian uses of uranium were developed.

A short history of uranium supply

Until the late 1940s, the only productive uranium deposits in the world were those in the Congo, and all

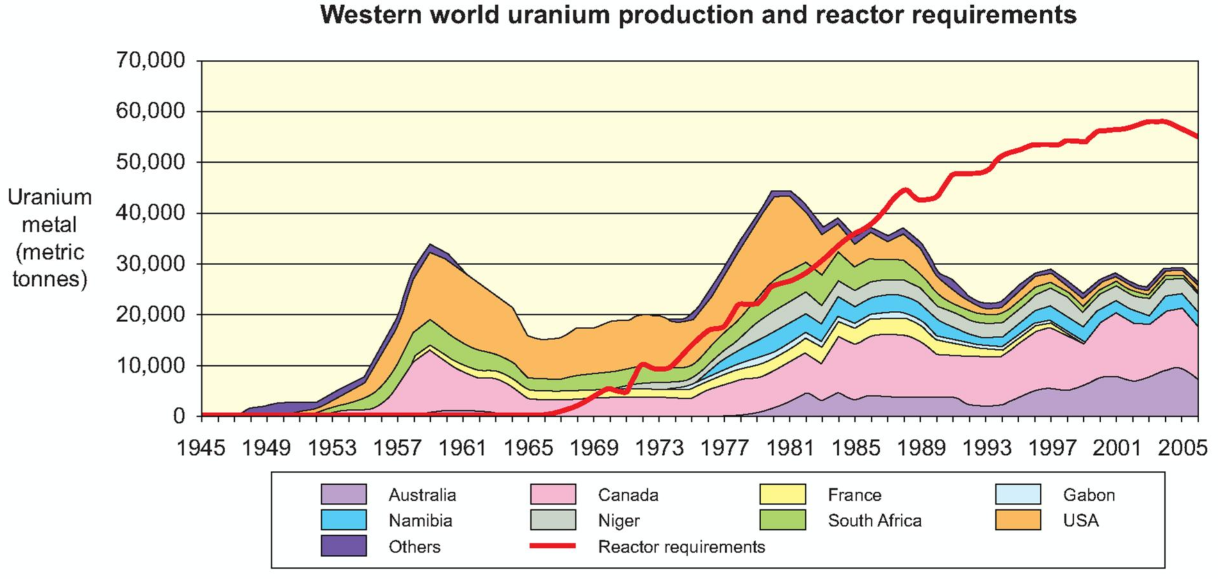


Figure 1: *Uranium production by country in the Western bloc, 1945-2005. Source: WNA. NB: No information is available for the former Soviet Union.*

of their output was bought by an Anglo-American joint-venture for weapon production (Goldschmidt, 1982, pp. 52-3). The Cold War sparked a flurry of exploration projects by the protagonists interested in developing a nuclear arsenal. Until 1969, the demand for natural uranium was very much driven by military needs. The aim was to mine those deposits that were most accessible so even low-grade deposits were mined. In the US, mining states were located in the Rocky mountains (Wyoming, Colorado and Utah) and in the southern part of the country (Texas, Arizona and New Mexico). France discovered indigenous resources and developed mines on its own territory (mostly near Limoges in Central France) while the UK secured resources in Canada and South Africa.

From the end of the 1960s, following the development of nuclear electricity generation, uranium demand for civilian uses picked up (as the red line in Figure 1 shows), with a range of consequences. In 1968, the US authorised private ownership of uranium (which had until then been a restricted, military material), creating a civilian market for the commodity. New deposits were found and new producers came into play, including African states such as Gabon, Niger and Namibia, and later, Australia. However, uranium was still constrained by its status as a military and strategic material, which prevented it from being freely traded. First, two distinct trade zones developed, one bringing together suppliers and consumers in the Western world, Australia and Africa, the other linking the Soviet Union, Eastern Europe and China. Before the 1990s, no trade took place between these zones. Second, most uranium supply agreements were signed into long-term contracts between suppliers and customers, where strategic and diplomatic elements played a huge role. France, for example, acquired a quasi-monopoly on uranium deposits in Niger, its former colony. Uranium was not and is still not traded on mercantile exchanges: only small quantities (between 10 and 15% of world production) are traded on the **Spot market** for short-term, one-off deliveries. This means that, today, most uranium is traded within long-term contracts (typically 12-15 years).

By the late 1980s, the early players were beginning to see a reduction in their output of uranium: production in the USA was down to a trickle and the last uranium mine in France, Le Bernardan mine, closed in 2001. This was partly to do with the growing relevance of the cost parameter; by the late 1980s, very little uranium was needed for what had previously been overriding strategic purposes, which were insensitive to costs. The less productive mines were shut and mergers between producers took place. What is more, following the fall of the Iron Curtain, a large amount of military uranium was converted to civilian use in the US and in Russia, with the result that natural uranium production and prices became seriously depressed. Military sources are now running low and prices have recently picked up again, rekindling mining and exploration efforts worldwide and bringing the current annual production to almost 40,000 tonnes of uranium metal a year.

The pragmatics of the nuclear renaissance

The physical principles for nuclear electricity generation are well known. The controlled disintegration of atoms in a reactor's core creates a chain reaction and produces energy in the form of radiation and heat, which is then transferred to a coolant (water or CO_2). The thermodynamic movements created in the heated coolant are used to rotate electricity-generating turbines. Only a limited number of materials are suitable for nuclear electricity generation, of which uranium is the best known and the most extensively mined, but other naturally occurring (thorium) or manufactured (plutonium) elements can also be used.

Today, civilian nuclear programmes shape the demand for uranium – both in terms of sheer volumes of material but also the dominant sites of production. Most of the 440 reactors currently in operation have been built in industrialised countries (Figure 2), with designs that differ in terms of:

- the type of uranium compounds they use (natural or enriched)
- the nature of the core **moderator** (graphite, water, heavy water)
- the nature of the coolant (boiling water, pressurised water, gaseous CO_2)
- the capacity of the reactor
- the national origin of the design (USA, Russia, Canada, France, Germany, the UK, Japan).

It is possible to identify worldwide networks of influence for every design: Canada and South Korea for the Canadian-designed CANDU; the UK for Magnox and Advanced Gas-cooled Reactors (AGR); Russia and its sphere of influence for Soviet-designed reactors. Specific designs have been developed even for the ubiquitous Pressurized Water Reactors (PWR) and the Boiling Water Reactors (BWR), although these are far from being standard, due to technical considerations

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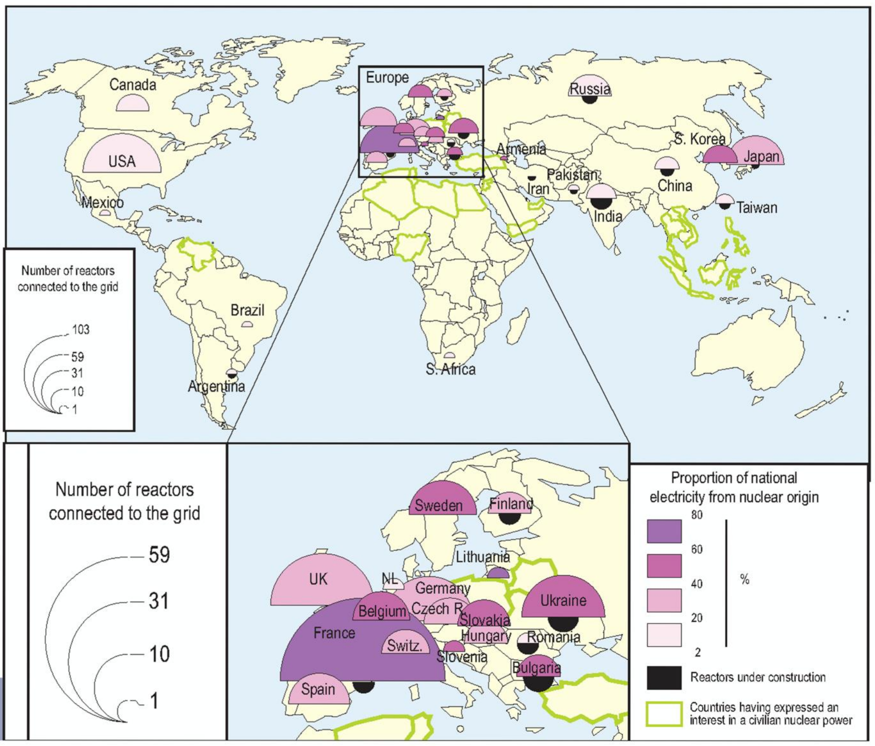
and differences in the normative conditions imposed by national regulators. For the last 20 years, however, the number and spatial distribution of nuclear reactors have largely remained the same, since very few reactors were built between the mid-1980s and the first years of the twenty-first century. As a consequence, the nuclear supply chain has been adjusted to service a fixed pool of reactors of known design.

The changes brought about by increased demand for nuclear material, products and services (the industry forecasts that nuclear capacity will have doubled by 2030) are substantially modifying the existing geography of nuclear power and the structure of the supply chain, as half of the 30 new reactors currently under construction are being deployed in developing and intermediate countries where electricity is in high demand and electricity production facilities are inadequate. Moreover, more than 20 countries, including newcomers such as Yemen, Libya, Venezuela, Indonesia and Nigeria, have expressed interest in developing or re-launching a nuclear programme to produce electricity or to desalinate seawater in the future (US CICNFC, 2009, p. 9).

Given this increased and geographically redistributed demand, it is questionable as to whether the capacity of the nuclear supply chain is sufficient to provide the necessary services and materials, especially in view of the adverse impact of years of underinvestment on human resources, nuclear expertise and production infrastructures. For instance, despite its geological abundance, the supply of uranium is uncertain: the latest instalment of the authoritative source on uranium supply, the OECD's 'Red Book', estimates the amount of conventional uranium resources which can be mined for less than USD 130/kg to be about 5.5 million tonnes (OECD-IAEA, 2008) – that is about 85 years of consumption at the current level of 65,000 tonnes per year, and about 45 years at projected consumption levels of between 94,000 and 122,000 tonnes. What is questioned is not the absolute quantity of uranium available for mining, but the feasibility of extracting and transforming ore economically and at a pace compatible with the rhythm of nuclear new-build. As the OECD puts it: 'Given the long lead-time typically required to bring new resources into production, uranium supply shortfalls could develop if production facilities are not implemented in a timely manner' (NEA-OECD, 2008). This statement is true not only of uranium mines but also of all the facilities within the fuel cycle.

Figure 2: *Spatial distribution of nuclear reactors worldwide.*



Producing and transforming uranium: the fuel cycle

A few technical indications

What makes uranium different from other energetic materials is the number and complexity of the industrial steps necessary to transform it from an ore into a fuel. Uranium mining is the first step in the 'nuclear fuel cycle' – the succession of steps that transform natural uranium into nuclear fuel through mining, milling and concentration/refining, conversion, enrichment and fuel fabrication. Every step technically follows from the preceding one, but within the industry a distinction is made between the 'open' nuclear fuel cycle (where spent fuel is treated as a waste) and the 'closed' cycle, where plutonium and uranium are recovered from spent fuel to make new fuel.

After uranium ore has been mined, mechanical and chemical processes are used to separate uranium from the ore tailings to produce uranium concentrate, known as 'yellowcake'. Some technological strands (such as Canadian CANDU reactors) directly use natural metallic uranium as the fissile element in nuclear fuel, but most of the reactors functioning in the world today use 'enriched' uranium. Natural uranium is composed of the isotopes U238 (99.2%) and U235 (about 0.7%), the latter being less stable than the former. Enriched uranium has undergone treatment to increase the proportion of U235 to 3.5% (for electricity generation purposes).

To enrich uranium, yellowcake first needs to be converted into a gaseous compound called uranium hexafluoride. Enriched uranium is then oxidised and manufactured into fuel pellets, themselves assembled in fuel elements that are placed in reactor cores. When the fuel elements enter the reactor's core, they initiate a chain reaction. Neutrons are emitted which in turn break up atoms, releasing further neutrons, sustaining the reaction. Unlike fossil fuels, nuclear fuel is a highly engineered product that has to be able to withstand very high temperature and radiation levels while delivering an optimal amount of energy. Its manufacture requires a variety of industrial skills in uranium physics and chemistry, metallurgy and thermodynamics.

The successive steps in the nuclear fuel cycle are not performed at the same locations and the geography of the uranium fuel cycle involves linkages between different countries, places and industrial actors.

A specific geography of production

Unlike fossil fuels, which are extracted in many locations around the world by a large number of industrial actors (Bridge, 2008), most uranium is extracted by a handful of actors in very few places. As Figure 3 shows, the main producers are central Asia (Russia, Uzbekistan, Kazakhstan), Niger, Namibia, Canada and Australia. There is now very little mining in Western Europe, and South-East Asia and South America largely remain out of the picture.

This spatial concentration of mining has been reinforced by the closure in the 1990s of unprofitable mines. Since 2001, new small-scale mining ventures have started up (especially in the US) to take advantage of higher uranium prices. However, their impact on uranium supply is not very great because their low and fluctuating levels of production precludes them from entering multi-year contracts with utilities, and they have been hit the hardest by the economic crisis that started at the end of 2007.

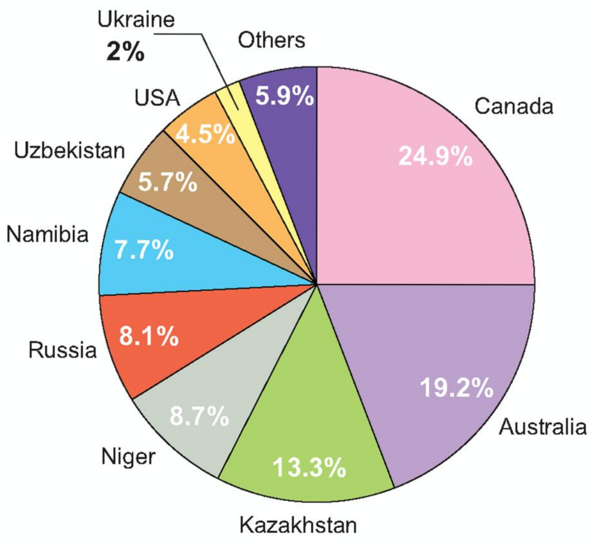


Figure 3: *Distribution of uranium production by country (2006). Source: OECD.*

Inside the producing countries, most uranium generally comes from just a handful of mines. For example, all of Australia's uranium comes from just three mines. In Canada (the dominant natural uranium producer in the world), during the last two decades the centre of gravity of the mining industry has shifted from Ontario to Saskatchewan, following the discovery there of high-grade deposits. The number of mining and milling (raw ore treatment) sites has sharply declined and, today, just two mines (McArthur Lake and Rabbit Lake) produce nearly a fourth of the natural uranium mined worldwide, while the milling of raw ore in Canada depends on two mills at McClean Lake and Key Lake.

The sector is also very concentrated in corporate terms. Uranium extraction is performed by both private companies (Rio Tinto) and state-owned mining conglomerates (Kazakhstan), but eight major players account for more than 85% of ore production.

The presence of state-owned entities in uranium mining is a legacy from the past: the strategic nature of uranium supply meant it was necessary for states to take over uranium mining and, potentially, other steps of the cycle as well. France's Areva and Russia's TVEL are integrated companies that offer services for the entire fuel cycle, from mining to fuel fabrication. Most other companies specialise in specific steps of the cycle.

The spatial and corporate structure of mining is replicated at the other steps in the cycle. The entrance barriers to the industry are very high: the amount of capital needed, the technological complexity of the plants and the strategic nature of many technologies involved keep many potential economic actors at bay (NEA, 2008a). Very few countries have the technical capacity to perform uranium conversion and enrichment.

Figure 4 presents the location of current conversion and enrichment plants in the world and shows the sparse distribution of uranium transformation facilities: few commercial conversion and enrichment plants are active today, and not all of them can

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	Company	Type	tonnes U	%
1	Cameco (Canada)	Publicly traded	8249	20.9
2	Rio Tinto (UK-Australia)	Publicly traded	7094	18.0
3	Areva (France)	State capital	5272	13.4
4	KazAtomProm (Kazakhstan)	State company	3699	9.4
5	TVEL (Russia)	State company	3262	8.3
6	BHP Billiton (UK-Australia)	Publicly traded	2868	7.3
7	Navoi (Uzbekistan)	State company	2260	5.7
8	Uranium One (Canada)	Publicly traded	1000	2.5
	Total top 8		**33,704**	**85.5%**

Table 1: *Major uranium producers, 2006. Source: World Nuclear Association.*

operate at full capacity because of underinvestment during the 1990s. In the Western world, for example, there are only six enrichment plants. Fuel fabrication is more widespread, with 23 active industrial sites. This sparse industrial network has two consequences. First, industrial capacity is not adequate everywhere. As the Nuclear Energy Agency puts it:

> *'Conversion capacity exceeds requirements in the European and North American regions, while imports are needed in the Pacific region. Enrichment capacities exceed requirements in the European region but requirements exceed existing capacities in the North American and Pacific regions. Fuel fabrication capacities are sufficient to meet requirements throughout the OECD area'* (NEA, 2007, p. 5).

Second, because the fuel cycle industrial structure is both sparse and unevenly distributed (globally and inside countries themselves), the entire system relies heavily on flows and transportation at each step of the fuel cycle and between fuel fabrication facilities and final consumers (electric utilities). As Figure 4 shows, there is a fundamental mismatch between the location of uranium deposits likely to be mined in the future and the location of the facilities needed to process the raw material. It is due to the hazardous nature of uranium that these movements, both between steps in the fuel cycle and beyond it, are so politically sensitive and logistically difficult. Moving radioactive cargoes by ship, for example, requires regulatory oversight, which is one of the reasons why shipping companies are increasingly reluctant to carry such cargoes.

Problematic flows

Nuclear materials are classified as 'dangerous goods' and, as such, their transportation is subject to a set of international regulations developed by the International Maritime Organization (for shipping) and the United Nations (for road and rail transport). These regulations apply to the documents needed to

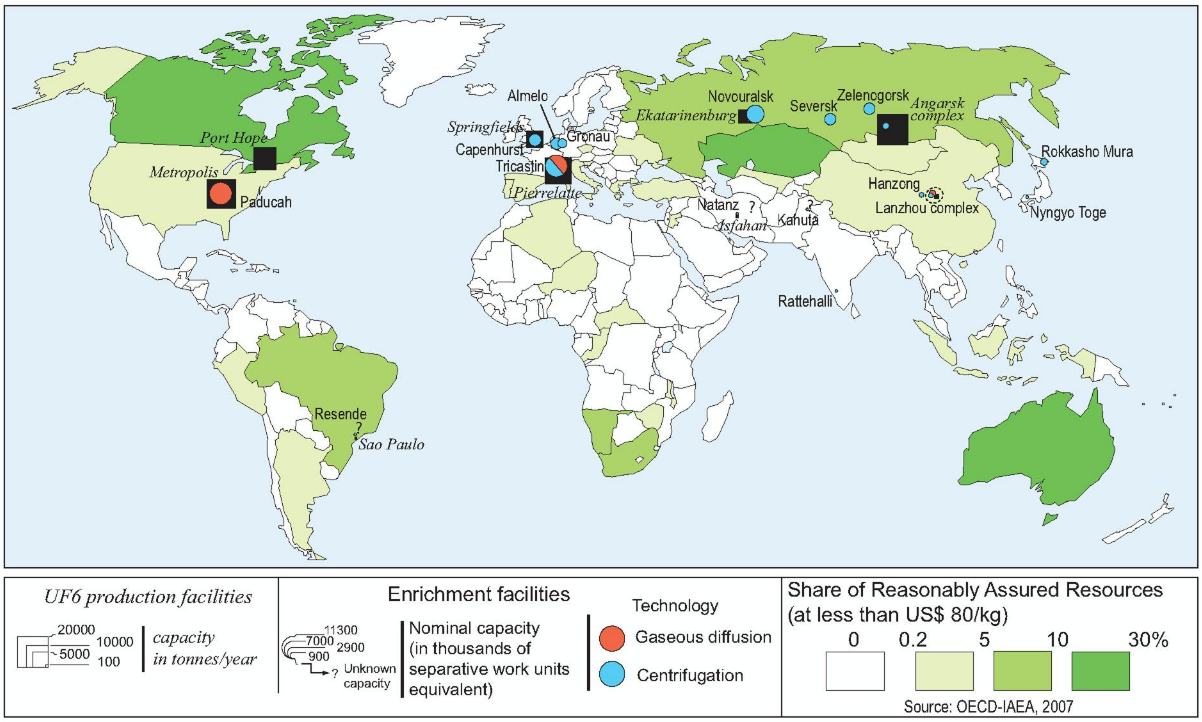


Figure 4: *Share of world uranium reserves (for an extraction cost of below US$ 80/kg) and industrial structure of the upstream (pre-use) uranium cycle. Source: OECD/NEA.*

transport radioactive materials and also determine best transportation practices, designed to minimise risks for workers, the public and the environment. Applying these regulations drives up the cost of transport, and there is no guarantee that a delivery will be allowed. Indeed, according to the IAEA, 'denials of shipments' are on the rise as port authorities, customs or nuclear regulators delay or forbid some shipments of nuclear materials, costing the companies such huge sums in penalties that some of them have left the business altogether: 'We refuse to transport all dangerous cargo, all the more radioactive cargo, because the safety constraints are too high and not proportional to the profitability of these operations' (e-mail message, shipping company executive, June 2008).

The shipping companies are also reluctant to transport nuclear materials because they fear the bad publicity that would follow if anything went wrong, or if environmental activists decided to target a shipment (interview, dangerous cargo manager, September 2008). In summary, companies whose business includes transportation of nuclear materials are exposed to risks which they may not always be willing to take, including denial of shipments. Clearly this has implications for the future of the nuclear power industry, given its proposed expansion and the associated increase in demand for transportation of dangerous goods.

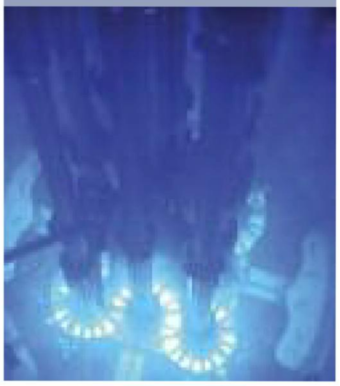
The politics of the renaissance

The renaissance: a prelude to further nuclear proliferation?

It is because of the dual use of uranium, for energy production and weapons manufacture, that its supply and transformation are subject to such close political scrutiny at all levels, from local to international. For the international community, the dilemma is clear: on the one hand there is the desire to increase the use of nuclear power as a so-called 'clean' form of energy. On the other there is a reluctance to disseminate knowledge relating to transformation technologies, and to enable new nuclear countries to develop fuel cycle infrastructures, because of the possible 'misuse' of the technology for military purposes.

Between the 1950s and 1970s, France, the UK and India (among others) developed their arsenal of atomic weapons using plutonium extracted from spent, non-enriched nuclear fuel because they did not have access to the uranium enrichment technologies necessary to create uranium-based weapons (Goldschmidt, 1982). While the USA was keen to promote the use of civillian atomic energy abroad (mainly due to the benefits US companies would receive through extracting and exporting uranium), they were also concerned that the spent fuel would be kept by foreign countries and reprocessed to extract plutonium for weapons. As such, the US Atomic Energy Act of 1954 stated that all uranium sourced from the USA had to be returned there following its use. However, the advent in the 1980s of cheaper, faster and technologically simpler uranium enrichment techniques based on centrifugation meant it was much easier to build a nuclear arsenal from enriched uranium rather than from plutonium. This was one of the reasons for the international anxiety when Saddam Hussein purchased uranium from Niger, and imported what were alleged to be components for the centrifugation process. There are similar anxieties today about Iran's ability to enrich uranium, despite that country's claim that the material is being produced to make fuel for nuclear reactors rather than nuclear weapons.

Given that enriched uranium can now be manufactured with limited access to sophisticated technology, there is a greater than ever need for non-proliferation measures, which since the 1950s have been based on bilateral and multilateral export controls. The system of export controls hinges on a series of legal procedures aimed at preventing non-nuclear weapon states from acquiring the materials and the technologies necessary to the development of atomic weapons. First, the international community requires that countries involved in nuclear trade sign the Non-Proliferation Treaty that was concluded in 1968. While the Treaty reaffirms the rights of any country to develop nuclear energy for peaceful purposes, exports of nuclear materials or technologies are subject to site visits conducted by the International Atomic Energy Agency (IAEA) and multilateral controls. Until the early 1990s, the Treaty was weakened by the unwillingness of some major nuclear suppliers (such as France) to sign it (Jabko and Weber, 1998) and it was not successful in preventing India from diverting Canadian civilian technologies to make its first bomb in 1974. A second set of procedures is based on *a priori* export control performed by informal groups – the Zangger committee (since 1971) and, since 1975, the Nuclear Suppliers Group (NSG) set up after the Indian atomic



bomb test (IAEA, 2005). The NSG guidelines allow national authorities to block the export of any materials and technologies (not necessarily nuclear) when a strong proliferation suspicion exists. However, the example of the Pakistani network led by A.Q. Khan has shown that the worldwide control of precursor materials and technologies has not been entirely successful at preventing proliferation. A third and final set of mechanisms comprises country-specific, bilateral regulations that require assurance from customers that uranium will only have civilian applications. For example, before an industrial company can purchase Australian uranium, a bilateral treaty has to be signed between the country where this company has its base and the Australian government. Until recently, that has prevented trade from taking place between Australia and Russia.

For new entrants to the industry, these regulatory constraints and the direct involvement of foreign governments at all levels in the nuclear economy introduce a strong geopolitical risk in the provision of nuclear materials, products and services. The example of Russia cutting or reducing natural gas supply to Ukraine, Belarus and Georgia on political and economic grounds is a powerful deterrent to a similar dependency within the nuclear industry, and newcomers have been seeking ‘assurances of supply’. The IAEA has tackled this topic since 2005, advocating multilateral arrangements for nuclear supply and the creation of multinational industrial facilities (IAEA, 2006). Altogether, the trend seems to be towards a relaxing of export control mechanisms and the ‘normalisation’ of uranium, as exemplified by the nuclear co-operation treaties signed by India with the USA and France in the spring of 2008.

A controversial nuclear future

Even if they have not received much publicity, the structural constraints relating to the provision of nuclear materials stand in the way of energy security in a low-carbon era. This is of particular concern in the Western world where energy security concerns are a major driver of the redevelopment of nuclear power. However, the most politically sensitive issues in the West are not proliferation or assurance of supply, but the cost of nuclear redeployment compared with other low-carbon energies such as solar, wind and wave power. It is extremely difficult to provide a balanced assessment of the true cost of nuclear power, because recent studies tend to contradict one another. In a recent meta-study, Greenpeace has argued that all studies favourable to nuclear power are based on unrealistic assumptions (Thomas *et al*., 2007), a view reinforced by the lack of recently completed facilities, which could provide insights relating the true costs. What is clear is that in liberalised electricity markets, the very high up-front cost of building a new nuclear plant (several billion pounds) make such ventures both risky and potentially unprofitable, at least without support in the form of high carbon taxes on fossil fuels, direct subsidies or tax credit (Taylor, 2007).

Accordingly, some critics have argued that redeveloping nuclear power would divert scarce financial resources away from other means of power production, and that money could be better spent developing high-tech renewables than subsidising the nuclear industry (Elliott, 2006). Others emphasise the important role of nuclear power in providing baseload electricity, and of the need to move the industry forward by using new types of materials and technologies – for example, using depleted uranium, thorium and plutonium (Kidd, 2008).

Conclusion

This rather open conclusion testifies to the fluidity of the political landscape of uranium and nuclear energy generation: the new geography of the fuel cycle we have been exploring is still very much in the making and this creates opportunities as well as uncertainties for the large-scale redevelopment of nuclear energy – the so-called ‘nuclear renaissance’. The problems linked to the spatial distribution of the industry, and the fact that just a few companies make up such a large proportion of it, are exacerbated by the problematic flows of materials, themselves shaped by economic, political and cultural factors.

Past and present attitudes to materials and technologies among multinational institutions, national authorities and the corporate sector have created obstacles for the expansion of the industry, potentially limiting its ability to respond to the ever-increasing demand for electricity. Not only does the nuclear industry need to revamp and diversify its industrial structures, it also needs to modify attitudes towards uranium and the regulatory frameworks that constrain its circulation. That requires the promotion of uranium as a ‘normal’ commodity, free from military and political interferences, but also the development of technical education in countries that have expressed an interest in developing or redeveloping nuclear power. The future of the industry depends in part on its capacity to modernise its supply structures, and also on its capacity to convince policymakers and the public that nuclear electricity does indeed have a role to play in low-carbon energy provision.

Glossary

Fissile: A material is said to be fissile when it is able to trigger and sustain a chain reaction. Most radioactive materials are not fissile.

Moderator: A medium that reduces the speed of fast neutrons, thus enabling their use for sustaining a controlled chained reaction.

Spot market: A market in which commodities or securities are sold for cash and delivered immediately. Such markets can be either publicly or privately organised and operated.

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Useful websites

The publications of the French Commissariat à l'Energie Atomique are a good free resource in English about energy issues:

Energy handbook:
www.cea.fr/content/download/4641/27568/file/memento2008.pdf

Nuclear power plants in the world:
www.cea.fr/content/download/4667/27759/file/Elecnuc2008.pdf

The World Nuclear Association website has good summaries of nuclear energy topics: *www.world-nuclear.org*

The Key World Energy Statistics from the International Energy Agency is a useful free resource: *www.iea.org/textbase/nppdf/free/2008/key_stats_2008.pdf*

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