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The Waste of the World

The geography of the nuclear fuel cycle : a material analysis

DRAFT VERSION : DO NO QUOTE WITHOUT PERMISSION.

Introduction

Current geographical thinking has seen a return to "materiality" – that is, serious consideration of the social role of objects in contemporary societies. Initiated within consumption geographies, the material turn aims to bring theoretical thinking beyond the standard conceptualisation of objects as substitutable "commodities" and consider their cultural meaning and social agency. Applying the "materiality" framework to geographies of production has proven somewhat difficult though, because cultural analyses do not readily fit into the assumptions and practices of political economists and corporate actors. To render matter economically tractable on the production side, a set of qualitative and quantitative procedures (abstraction, categorization, material accounting and modelling, pricing) have been developed that get rid of the meanings associated with matter and objects. The production side is more concerned with the physical, technical and financial aspects of material transformations than with the socio-cultural value of products or the production process.

As a consequence, cultural approaches to commodity production are often seen as irrelevant in corporate environments. This is especially true for commodities which are not marketed directly to the public: the materiality framework seems to make more sense for mass consumption products that rely on advertising and marketing (say, vodka or MP3 players) than for intermediary products such as steel. Bakker and Bridge however, argue that "industrial commodities – those that come closer to a classic definition of fungible commodities – should not be exempt from this cultural analysis" (Bakker and Bridge 2006, 13). This would probably require an understanding of how matter is perceived throughout its social life and how these differential perceptions impinge on economic aspects and material transformations themselves, beyond the production/consumption dichotomy.

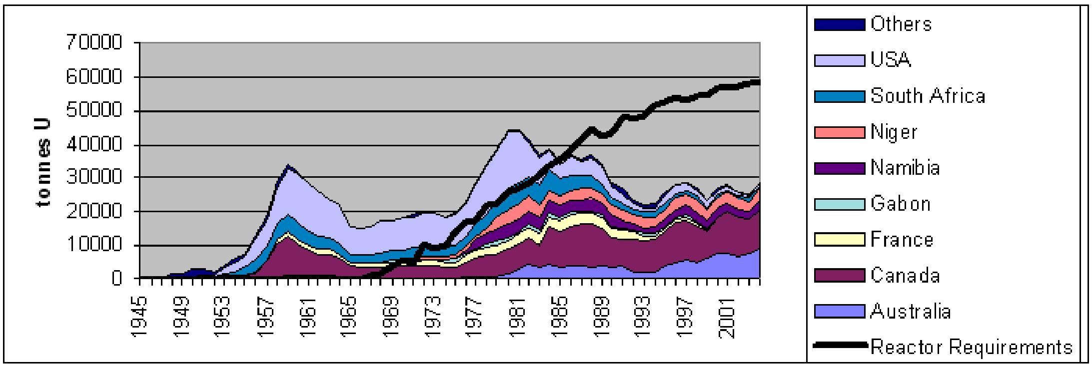
In this paper, I would like to engage with these issues by providing an analysis of the geographies of the uranium fuel cycle. In the corporate and institutional literature, little attention is generally devoted to the pragmatics of uranium mining and transformation, which are generally presented in statistical tables, with little consideration for many material aspects that frame and constrain supply and demand: historical legacy, technical hurdles to exploitation, unforeseen events, uncertainties, political interventions. From a cultural geography point of view, uranium provides an interesting entry point into a material 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, a chance for regional development, etc. What I would like to show by unpacking the geographies of the fuel cycle is that these conflicting constructions of uranium have had substantial consequences on the production and circulation of uranium itself.

The paper is organized as follows. First, I provide contextual elements on the legacy of uranium exploitation as an energetic material. Second, I introduce the notion of "fuel cycle" and analyse its geographical dimension. Finally, I evoke some problems relative to nuclear flows that are directly linked to the cultural appreciation of uranium and nuclear materials.

1. Uranium : a "renaissant" energetic material

Whereas fossil fuels have been used extensively for over two centuries, are remarkably distributed on the planet and are relatively easy to transform, uranium is the exact opposite. Military uses were predominant until the late 1960s and it is only in the late 1950s that civilian uses of uranium for electricity generation developed, generating a growing demand for the material. For a long time however, supply was problematic because of the relative scarcity of uranium deposits.

Until the late 1940s, the only productive deposits in the world were located in the Congo and all of their output was bought by an Anglo-American joint-venture for weapon production (Goldschmidt 1982, p.52-53). The Cold War sparked a flurry of exploration projects. Until 1969, the demand for natural uranium was very much driven by military needs, as the black line in Graph 1 shows. Even low-grade deposits were mined as states set out to mine the deposits that were most accessible to them. In the US, mining states were located in the Rocky Mountain Range (Wyoming, Colorado and Utah) and in the southern part of the country (Texas, Arizona, New Mexico). The UK secured resources in Canada and South Africa. France discovered indigenous resources and developed mines on its own territory (mostly near Limoges, in Central France).

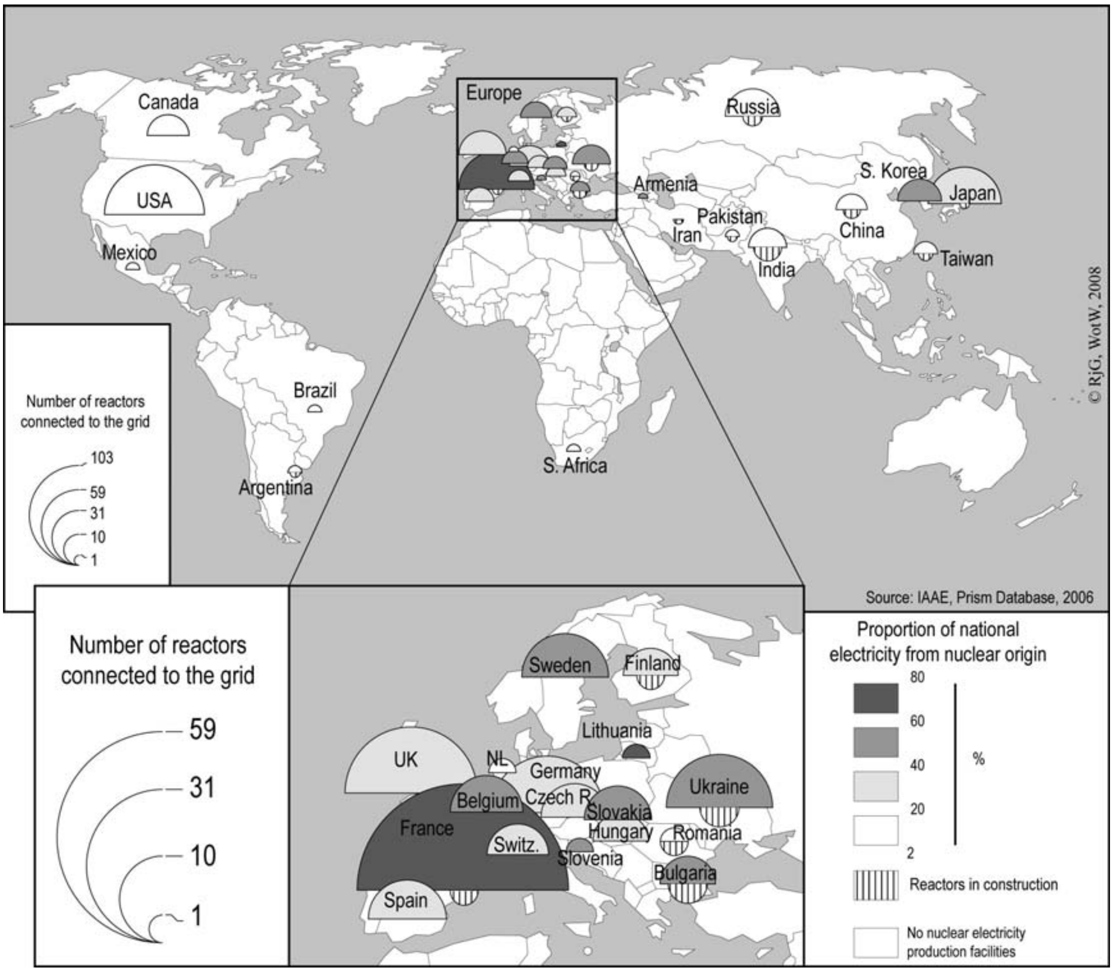


Graph 1: Uranium production by country in the Western bloc, 1945-2005 (source : WNA)

NB: no information is available on the production of the former Soviet Union.

From the end of the 1960s, uranium demand for civilian uses picked up. New deposits were found and new producers came into play: African states – Gabon, Niger and Namibia; and later, Australia. Beginning in the late 1980s, the early players saw their relative position dwindle: uranium production in the USA was down to a trickle and the last uranium mine in France, Le Bernardan mine, closed in 2001. Much of that evolution had to do with the growing relevance of the cost parameter, since so little uranium was then needed for those overriding strategic purposes which were insensitive to costs. The less productive mines were shut. What is more, following the fall of the iron curtain, a large amount of military uranium was converted to civilian use. In the 1990s, this source of uranium created an overabundant supply of uranium on the market and seriously depressed natural uranium production and prices. It is now almost exhausted and prices have recently picked up again, rekindling exploration efforts worldwide.

Another reason for this surge of uranium price is the worldwide nuclear “renaissance” that the industry has been experiencing since 2001. The number of electricity generating nuclear reactors is about 440 today but according to the World Nuclear Association, as of 2008, 30 new reactors are being built and 70 more are in an advanced state of planning. As many as 20 new countries have expressed interest in developing nuclear electricity. By 2030, the industry forecasts that nuclear capacity should have doubled, substantially modifying the map of nuclear electricity generation. As an indication of this trend, most new reactors currently being built are not in Western countries where a majority of the nuclear capacity is deployed, but in developing and intermediate countries where electricity is in high demand and electricity production facilities inadequate.



Map 1. Spatial distribution of current and future nuclear reactors worldwide.

The “renaissance” is all the more spectacular that the nuclear industry spent some twenty years in the wilderness after the very serious accident at the US power plant at Three Mile Island in 1979 and the Chernobyl catastrophe of 1986 in Ukraine. Plans to build new reactors were cancelled. Most significant investments in nuclear technology were frozen, including investments in the search of new uranium deposits or the upgrade of existing mines and transformation facilities. The industry attracted suspicion and was fiercely criticized by the ecological movement. It seemed outdated, dangerous and its future was uncertain. A few countries, like Sweden, Italy and Germany, chose to pull out of nuclear electricity generation altogether.

A radical change of context is the main driving force behind the “Renaissance”. The conjunction of high electricity demand, geopolitical and climate concerns over fossil fuels and fluctuations in oil prices have contributed to put nuclear energy and uranium back on the map. Nuclear energy is now presented as integral to sustainable, carbon-free development -- a rational solution to the growing energy hunger, which is only impeded by the environmental movement’s political opposition.

This presentation, however, overshadows some fundamental aspects of nuclear electricity generation. First, nuclear energy accounts for about 3% of the energy consumed worldwide. Even in France (which produces 78% of its electricity from nuclear sources) nuclear energy accounts for only 18% of total energy consumption, with fossil fuels covering most energetic needs. Doubling nuclear electricity production would only fill about 10% of the world’s energetic demand. It is better to think of nuclear power not as a substitute for fossil fuels but as a balancing element in energy mixes worldwide.

Second, it does not take into account the constraints that bear upon the development of nuclear energy in the future, and most notably the peculiar geographies of uranium production and transformation that are a historical legacy: the obstacles to the renaissance are not only political, but material also. Many upgrades to the existing obsolescent production and transformation structures will be needed to fulfil a natural uranium demand that is likely to double in the next twenty years.

2. Producing and transforming uranium: the fuel cycle

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 radiations and heat, which is then transferred to a coolant. The thermodynamic movements created in the heated coolant are used to rotate electricity-generating turbines. Only a limited number of materials (known as “fissile materials”) are amenable to nuclear electricity generation. Uranium is the best known and the most largely mined but other naturally occurring (thorium) or artificial (plutonium) elements can also be used.

There are different technological designs for nuclear reactors, with varying parameters, most notably the type of uranium compounds they use (natural or enriched); the nature of the core moderator (graphite, water, heavy water); and the nature of the coolant (boiling water, pressurized water, carbon dioxide). These competing designs structure the way the industry operates. In a given country, the dominant technology will bear an imprint on the way the whole national industry is organized. It is possible to distinguish worldwide networks of influence for every technical strand: Canada and South Korea for the Canadian-designed CANDU[1], the UK for Magnox and AGR, etc. Specific strands have been developed even for the ubiquitous PWR and the BWR: designs are far from being standard, since technical considerations and normative conditions imposed by national regulators create unique conditions.

Transforming natural uranium for electricity generation is a complex task. Uranium mining is the beginning of 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 and 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 99.2% of one isotope, U238 and about 0.7% of U235, which is less stable. Enriched uranium has undergone a specific treatment to increase the proportion of U235. The enrichment process brings 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 oxidized and manufactured into fuel pellets, themselves assembled in fuel elements that are placed in reactors 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 manufacturing requires a variety of industrial skills in metallurgy, uranium physics and chemistry, thermodynamics, etc.

Counter-intuitively, the successive steps of the nuclear fuel cycle are not performed at the same locations and the geography of the uranium fuel cycle is an original one that links together many different countries, places and industrial actors.

Uranium production however is extremely concentrated. 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 Map 2 shows, very little mining is still done in Europe. South-East Asia and South America largely remain out of the picture. The main producers are central Asia (Russia, Uzbekistan, Kazakhstan), Niger, Namibia, Canada and Australia. This spatial concentration of mining has been reinforced by the experience of the 1990s, when unprofitable mines were closed.

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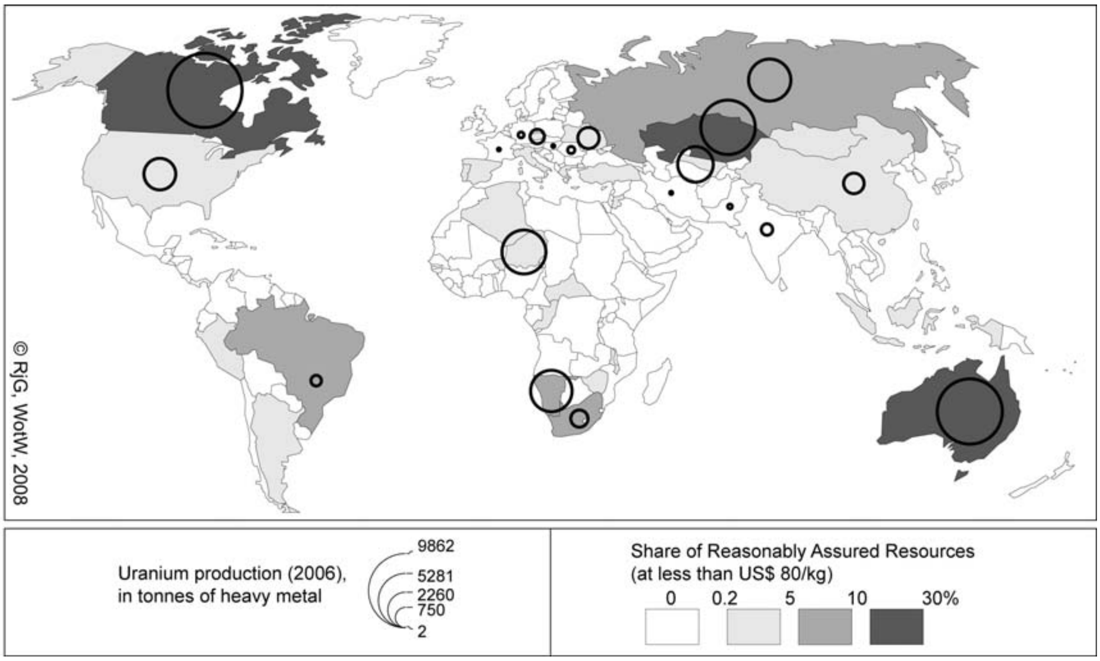
[1] There are currently nine CANDU reactors in operation or in construction outside of Canada: 4 in South Korea, 2 in China, 1 in Argentina and 1 in Romania. A second CANDU reactor is being built in Romania.



Map 2. Uranium production in 2006 and share of world uranium reserves (for an extraction cost of below US$ 80/kg).
Source: OECD/NEA

Inside the producing countries themselves, production generally comes from just a handful of mines. Just three mines provide the totality of the Australian uranium. In Canada (the first natural uranium producer in the world), the centre of gravity of the mining industry has shifted from the South of the country (Ontario) to the North (Saskatchewan) for two decades now, following the discovery 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 just two mills at McClean Lake and Key Lake.

Because of the few mining spots worldwide, the natural uranium supply system is not very resilient. Any incident can substantially impede production and bear on world prices. Canadian mines, for example, are subject to rigorous climate conditions and water is omnipresent in the region. For underground mines, a freezing agent has to be used in the shaft to prevent water seeping into the mine, which is a severe constraint and a technical liability. In October 2006, an inflow incident flooded the new Cigar Lake high-grade uranium mine, pushing forward the production phase from 2007 to 2010. The upwards drive of uranium prices has been compounded by the incident at Cigar Lake (which stable annual production should reach 6900 tU/year, i.e. 10% of world production). Other unexpected events can occur. In 2007, a world shortage of the special tires used by the 250 and 500 tonne-trucks used in opencast mining limited the production of uranium.

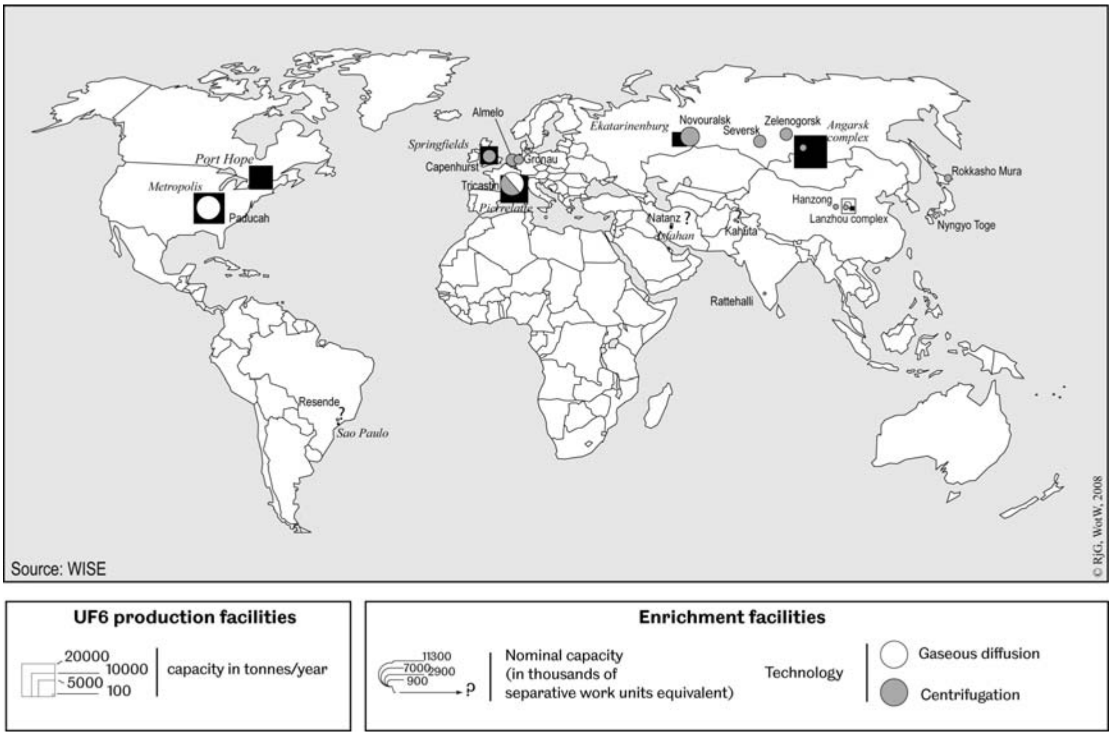
In corporate terms, the sector is also very concentrated. Uranium extraction is performed by both private companies (Rio Tinto) and state-owned mining conglomerates (Kazakhstan), but eight major players account for more than 85% of ore production.

	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

The presence of state-owned entities in uranium mining is a historical legacy again. The strategic nature of uranium supply meant it was necessary for states to directly take over uranium mining and potentially, other legs 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 specialize on specific legs of the cycle.

The spatial and corporate structure of mining is replicated at the other steps of 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. Very few countries have the technical capacity to perform uranium conversion and enrichment and this is as a strong structural constraint for further development of nuclear electricity.



Source: WISE

Map 3. Uranium hexafluoride and uranium enrichment facilities.

Map 3 presents the location of conversion and enrichment plants in the world and makes clear that that uranium transformation has a strong hierarchical structure: few commercial conversion and enrichment plants are active today and not all of them can operate at full capacity. 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 exceeds 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." (Nuclear Energy Data, 2007, p. 5)

Second, the fuel cycle industrial structure being at the same time sparse and unevenly distributed (globally and inside countries themselves), the entire system heavily relies on flows and transportation on each leg of the fuel cycle and between fuel fabrication facilities and final consumers (electric utilities). However, the flows and trade of uranium and uranium products face severe constraints, to which we shall now turn.

3. A problematic geography of flows

Much literature has been devoted to local visions of industrial sites (nuclear plants, industrial facilities) and has discussed perceptions of risk and acceptability (Zonabend 1993 [1989]). In most places where uranium products are handled on an industrial scale, local communities are generally supportive of the industry. This is not to say that dissent does not exist (especially when it comes to green field sites where new facilities are planned, for example waste storage facilities), but the monopolistic nature of nuclear facilities on a local scale, where most people depend on them for jobs, makes the expression of dissent difficult. On a national scale, public opposition to the nuclear industry can stall industrial development. In Australia, all new mining projects and plans to build new nuclear power plants have been mothballed in face of public opposition.

Likewise, cultural constructions have an impact on nuclear flows. Demonstrations occur frequently when high-level waste is sent back to producing countries after reprocessing. But there are three other aspects that are less well known and have a much greater industrial significance.

First, nuclear materials are enshrined in a complex set of regulations to ensure that they will not be put to military uses. To forestall proliferation, the international community requires that countries involved in nuclear trade sign the Non-Proliferation Treaty that was devised in 1974, after India used Canadian technology to extract military plutonium from spent fuel. Any country that would not sign the treaty and agree to have its installations controlled by the International Atomic Energy Agency (a part of the UN) would not be able to acquire nuclear materials or technologies from international suppliers. Some uranium producing countries have added national regulations that require assurance from customers that their uranium will have only 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 flows from taking place between Australia and Russia. The US went further, and the Atomic Energy Act of 1954 (article 123) requires that all foreign customers agree to ship back fuel from US origin back to the US. A similar treaty has been signed between Iran and Russia: Russia provides fuel for the nuclear power station it is building in Iran and will bring it back after use in the reactor.

Second, the sparseness of the industrial network, the complexity of conventional agreements and the constant involvement of states in nuclear trade supervision create potential hurdles for further expansion of nuclear power, because newcomers have to be assured that they will be able to access necessary materials and technologies – and that their suppliers will not yield to political pressures. The IAEA raised the topic of “assurances of supply” in a 2005 report that discussed the possibility of creating multilateral arrangements, including multinational industrial facilities:

> “The ‘assurance of supply’ value of a multilateral arrangement is measured by the associated incentives, such as: the guarantees provided by suppliers, governments and international organizations; the economic benefits that would be gained by countries participating in multilateral arrangements; and the better political and public acceptance of such nuclear projects. **One of the most critical steps is to devise effective mechanisms for assurances of supply of material and services, which are commercially competitive, free of monopolies and free of political constraints.** Effective assurances of supply would have to include back-up sources of supply in the event that an MNA supplier is unable to provide the required material or services.” (AIEA, Multilateral approaches to the Nuclear Fuel cycle, 2005, p. 3)

Third, transport companies have become increasingly reluctant to carry nuclear goods, for a variety of reasons. Nuclear materials are considered to be “dangerous goods” and as such, their transportation is the subject of a set of mean-specific international regulations (the IMDG code for sea shipping, the ADR convention for road transport, etc.). These regulations normalize the documents needed to transport radioactive materials and formulate best transportation practices to minimize risks to the workers, the public and the environment. These requirements drive the cost of transport substantially up, but are no guarantee that a transport will effectively take place. Indeed, port authorities, customs or nuclear regulators sometime delay or forbid certain shipments, costing the companies huge sums in penalties. As one large shipping company executive puts it:

> “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”. (Interview, June 2008)

Another issue raised by a dangerous cargo manager in a large shipping company is the bad publicity made to the company in case anything goes wrong or if environmental activists decide to pick up on a shipment (Interview, September 2008). In other words, radioactive materials have a huge potential to disrupt shipping operations within companies themselves and many will simply not take that risk. If uranium transformation companies have generally put in place resilient logistic chains for their current operations (including developing their own transport subsidiaries), the expansion of nuclear power will require more transports at an accelerated pace and will potentially face increased “denials of shipments” in IAEA jargon. These have so far primarily concerned medical radioactive sources but the IAEA and other industrial organizations worry that cultural opposition to uranium shipments among corporate actors jeopardize expanded trade and transport in the future. It is all the more important that uranium supply contracts for electricity generation are generally very long (5 to 15 years) and that contractual responsibility for the delivery rests with the provider.

Conclusion

In this short overview of the uranium supply system worldwide, we have insisted on material factors in order to move beyond simple commentaries on production statistics. These factors are not only technical: they incorporate attitudes to the material among multinational institutions, national authorities and the corporate sectors, both in the past and in the future. This example calls for an extensive definition of “cultural attitudes” when it comes to industrial commodities – and for careful consideration of their factual consequences.

Such an analysis is precious, because it helps cut through the nuclear companies public relation “spin”: the inevitability of “nuclear renaissance” seems less assured when the whole nuclear fuel cycle is analysed in material terms, incorporating the uncertainties in production, trade and transport. Under a confident public posture, the nuclear industry is at a crossroads, because the renaissance calls for an upheaval of industrial structures that still bear the legacy of national military build-ups. In the nuclear sector, there is a dialectical relationship between the national nature of early industrial and technological developments (under the control of nation states) and the efforts to turn nuclear electricity and uranium into casual industrial commodities

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