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The Global Uranium Market

And How it Might Change in the Wake of Fukushima

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Abstract

This paper provides a general introduction to the uranium market and to the formation of uranium prices. Historical price developments are discussed and an analysis of the market situation after the accident at the Fukushima Dai-Ichi Nuclear Power Plant is made.

Introduction

On 11 March 2011 an undersea earthquake of magnitude 9.0 shook the eastern coast of Japan's main Honshu Island. The quake and the subsequent Tsunami caused tremendous devastation and human suffering leading the Japanese Prime Minister to describe the disaster as the "toughest and most difficult crisis for Japan" since World War II [1]. The purpose of this paper is not to give an assessment of this tragedy as a whole, but rather to investigate the effects of to the accident at the Fukushima Dai-Ichi Nuclear Power Plant on the global nuclear energy industry, and in particular on the global uranium market.

In Section 1 of this paper the history and some unique properties of the uranium market will be described. Section 2 will provide an overview of the major forces that affect global uranium prices. As such, it will heavily draw upon an analysis of historical price developments and will look in particular at the uranium market developments in the wake of previous nuclear accidents. Finally, Section 3 will give an overview of global political reactions to the Fukushima Dai-Ichi accident and provides some simplified projections for the future of the uranium price.

Contents

List of Acronyms

NPP	Nuclear Power Plant
LCOE	Levelised Cost of Electricity
OECD	Organisation for Economic Co-operation and Development
HEU	Highly Enriched Uranium
GWe	Gigawatt Electric
CHF	Swiss Francs
Rp	Swiss Rappen
IAEA	International Atomic Energy Agency

R	Total Uranium Resources
IDR	Identified Resources
RAR	Reasonably Assured Resources
IR	Inferred Resources

1 Properties of the Uranium Market

1.1 Uranium: Where does it come from and what is it used for?

As far as natural resources are concerned, Uranium can be described as a fairly young commodity. Even though it has been on our planet for much longer than we have, significant human interest in this element only developed in 1938 after the discovery of nuclear fission by a group of scientists around Otto Hahn. This was followed by the construction of the world's first (artificial) nuclear reactor by Enrico Fermi in 1942. The nuclear arms race of the cold war and the rise of civil nuclear power in the 1960s both contributed to a very rapid increase in the demand for Uranium in subsequent years.

But where does Uranium actually come from? The chemical element U was formed in stars through the process of nuclear breeding (absorption of neutrons) and was released into space during supernova explosions. The energy we derive from Uranium today can thus be considered a form of solar energy that has been stored in nuclear cores for billions of years [2]. It is a relatively abundant element with an average concentration of around 2.7 ppm in the earth's upper crust (more than 650 times the concentration of gold [3]). The global distribution of Uranium, depicted in Figure 1, shows that Uranium resources have been found in many countries across the globe, making it an attractive resource from the point of view of energy independence. It can also be seen, however, that over 60% of identified resources are in only 4 countries: Australia, Kazakhstan, Canada and Russia.

Uranium can be mined in several ways. If the deposits are close to the surface, open pit mining is the simplest and most economic method. For deeper deposits, underground mining methods need to be used. Finally, in some cases "in situ recovery", a method where the uranium is dissolved in a solution and pumped to the surface, is chosen. In principal, all of these techniques are "conventional" mining methods and bear similarities to the extraction processes of other minerals.

After uranium is mined, it needs to undergo a significant number of processing steps until it can be used in civil or military applications. These steps will not be described in detail here. It shall only be stressed that additional infrastructure and expenditures are necessary for turning uranium ore into a product for the final consumer. While during the cold war the final products were mainly highly enriched uranium and plutonium for nuclear weapons, today they are primarily fuel rods for nuclear power plants (NPP).

1.2 How is uranium bought?

Unlike other energy carriers such as oil or natural gas, uranium is not traded on a commodity exchange. Prices and quantities of uranium exchanges

Figure 1: Global Distribution of Identified Resources (<USD 130/kgU)(Source: [4]

are typically negotiated directly between the buyer and seller and are thus not publicly available, making the price formation of uranium anything but transparent. The implication of this lack of transparency will be discussed in more detail in the following chapters.

Around 80 to 90% of worldwide uranium purchases are carried out in the form of long-term supply contracts [5]. These long-term contracts often involve fixed prices and regular deliveries over the period of several years. Most of the remaining purchases take place in the form of "spot market" transactions. Even though there is no actual marketplace where spot transaction are carried out, this term is still used to refer to transactions that take place on a short-term and irregular basis. Often this type of purchase is carried out through intermediate brokers and traders.

A typical customer of uranium (e.g. an operator of nuclear power plants) is likely to have procurement contracts with a number of different producers in order to reduce the risk of non-delivery. Purchasing strategies involving a mix of long-term and short-term contracts are also common. Choosing to obtain a certain share of the required uranium quantity on the spot market allows a customer to profit from potential price drops but of course also increases the exposure to rising prices.

2 Uranium Price Formation

As mentioned in Section 1, the uranium price formation is not very transparent. Details about the majority of uranium transactions are not publicly known, making the price formation a somewhat mystifying process. Over the last 30 years, however, two private consultancies, UxC and Tradetech, have become the de-facto authority for uranium price information. They determine weekly and monthly prices for uranium, as well as for uranium processing, based on surveys of key players in the industry. The Head of the Nuclear Fuel Department of the Swiss Axpo AG estimates that over 95% of all uranium deals are based on this type of price information [5].

Sections 2.1 and 2.2 provide some background information about the supply and demand of uranium. In Section 2.3 a simple theoretical model of uranium price formation will then be developed. Finally, in Section 2.4 the actual historical uranium prices will be presented and analysed.

2.1 Uranium supply

Total Uranium Resources (R) are conventionally divided into *Identified Resources* (IDR) and *Undiscovered Resources* (UR) [2]. Identified Resources are further divided into *Reasonably Assured Resources* (RAR) and *Inferred Resources* (IR).

$$IDR = RAR + IR \tag{1}$$

The difference between RARs and IRs is mainly the degree of reliability concerning the grade (concentration), amount, and distribution of uranium at a certain site.

Additionally, resources are grouped into categories according to the cost at which they are recoverable. Table 2.1 shows an overview of total global IDRs in the 4 different cost categories used by the OECD Nuclear Energy Agency and the International Atomic Energy Agency (IAEA) [4].

Identified Resources (IDR)	**2009 (1000 tU)**
<USD 260/kgU	> 6 306
<USD 130/kgU	5 404
<USD 80/kgU	3742
<USD 40/kgU[1]	> 796

Table 1: Global Identified Resources according to extraction cost. Source: [4]

The OECD and IAEA estimate of the global uranium used in 2009 is 61,730t. Taking the 2009 total IDR (<USD 260/kgU) and dividing it by this figure results in a yield of just over **100 years** at the 2009 rate of con-

sumption. If Undiscovered Resources (UR) are considered as well (including all cost categories), this figure increases to over **270 years**.

It is very interesting to note that for the last 25 years the estimates of global IDRs has roughly remained constant [2]. What this means is that uranium resources have been moved into this category at approximately the same rate as they have been mined. Over the same time frame the URs have also not markedly decreased. In other words, total estimated reserves (R) have approximately stayed the same over the last 25 years.

So far only the availability of uranium resources has been discussed, and not the actual supply. The supply, of course, depends on the market price and the cost of mining. A more detailed discussion of this interaction is reserved for later chapters. At this point it shall only be added that there are significant delays between the time of making a uranium discovery and actually being able to start mining. Depending on the complexity of the project, timescales of 5-10 years are typical.

2.2 Uranium Demand

While in the past a significant portion of the uranium demand came from the military, today the primary driver of demand is the global nuclear electricity generating capacity. In 2009 there were 438 nuclear reactors connected to electric power grids, providing a total capacity of 372.69 GWe (10^9 W electric). The global distribution of this generating capacity is shown in Figure 2. The corresponding estimated uranium demand was 61,730t, as given in the previous chapter.

In addition to the installed generating capacity, the so called capacity factor also directly influences uranium demand. This factor indicates the percentage of time during which a power plant operates at its installed capacity. The world average capacity factor has increased to around 80% today compared to roughly 70% in 1990.

Table 2 summarises the most significant factors that contribute to the demand for uranium.

It is very important to also look at the political and societal drivers that determine the demand for nuclear energy, and thus for uranium. Forces that contribute to an increase in demand are the desire for increased energy security and low carbon electricity. On the other hand, concerns about the safety and the environmental impact of nuclear reactors and the nuclear fuel cycle are exerting a downward pressure on the demand for nuclear energy.

2.3 Ideal Price Formation (Theoretical)

In this chapter simple models for the supply and demand curve of uranium will be developed in order to show how, theoretically, the uranium price is formed. As mentioned in Section 2.1, the different mining locations are

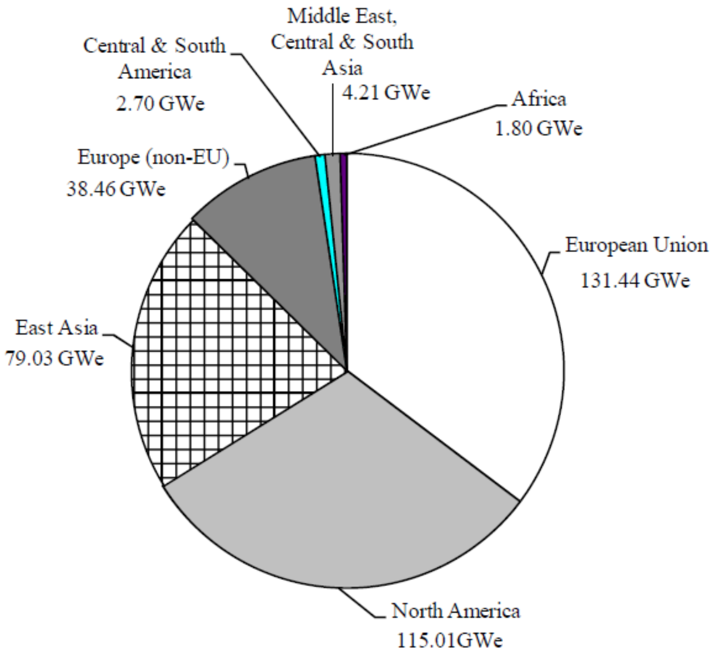

Figure 2: World installed nuclear capacity: 372.69 GWe net (as of 1 January 2009). Source: [4]

Factor	Relevance
Number of new reactors starting up	Loading a reactor for the first time requires 60% more fuel than during re-loads, amplifying the importance of this aspect.
Extension of operating life-times	Governments or regulating bodies can decide to extend the life-time of nuclear power plants beyond their design-life, increasing uranium requirements relative to the otherwise anticipated demand.
Fuel-cycle length	The time that a particular fuel assembly remains in a reactor can be varied, leading to different degrees of âburn-upâ. The demand for new fuel elements will vary accordingly.
Price of enrichment services	If uranium prices are high, a customer may choose to order fuel with higher enrichment levels. This is a way of extracting more useful material from the same amount of natural uranium but comes at a price.

Table 2: Factors affecting the demand for uranium

associated with different extraction costs. This leads to a so called merit order supply curve. Uranium from mines with low extraction costs are offered first and thus appear on the left hand side of a supply and demand diagram. Supply offers are then made in the order of increasing prices with the most expensive Uranium appearing on the very right of the merit order curve.

The uranium demand curve is very price inelastic, i.e. it can be assumed to be nearly vertical. The main reason for this is that nuclear fuel costs actually only make up a relatively minor percentage of overall electricity generating costs of a nuclear power plant. In [2] it is estimated that nuclear fuel costs amount to 0.67 Rp/kWh. The total levelised cost of electricity (LCOE) for nuclear power in Europe is estimated at around 5.5 Rp/kWh (around 60 USD/MWh) [6]. So the contribution of *nuclear fuel* to the LCOE is only around 12%. The contribution of the *uranium* costs to the LCOE would be even lower since fuel conversion, enrichment and fabrication make up almost half of the cost of the final nuclear fuel rod.

Thus, for the operator of a nuclear power plant, the price of uranium has very little influence on the quantity of fuel demanded. It will be attempted to operate as close to full capacity as possible in order to cover the fixed costs of the NPP and to contribute towards writing off the large investment that an NPP constitutes. The ability to substitute some of the uranium purchases by increasing the enrichment level of the fuel theoretically introduces a small degree of price elasticity. This effect is considered to be minor and is therefore neglected in this simplified model.

Figure 3 shows how the supply merit order curve and the inelastic demand curve should theoretically lead to a market price P at quantity Q. It can be seen that the clearing price is determined by the cost of the most expensive uranium source that needs to be included from the merit order curve at the demanded quantity. How valid this simplified model is will be looked at in the next section where historical uranium prices will be analysed.

2.4 Analysis of historical uranium prices

Williams [5] divides the history of the uranium market into four periods.the history of the uranium market is divided into for periods:

1. The Cold War: Uranium mined for weapons (1940-1969)
2. Bright Prospects: Inventory Build Up (1970-1984)
3. Buyer's Market: Inventory Reduction (1985-2004)
4. Seller's Market: The Renaissance (2004-????)

During the first period, demand for uranium was heavily driven by nuclear weapons programs. Very large amounts were stored in the form of highly enriched uranium (HEU) or processed to plutonium.

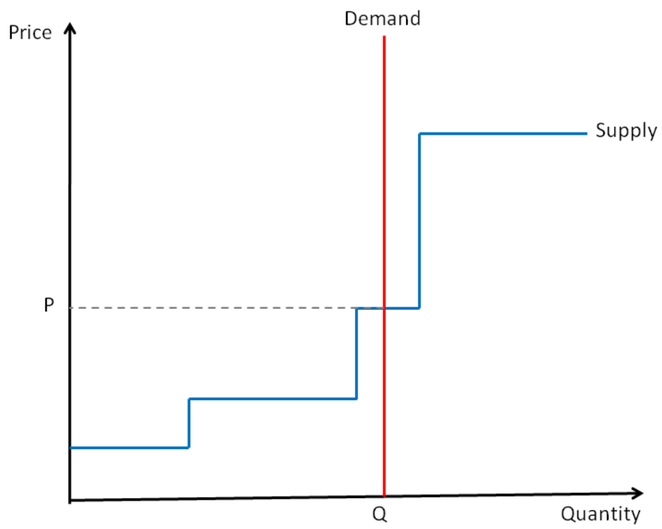

Figure 3: Simplified Model of Uranium Price Formation

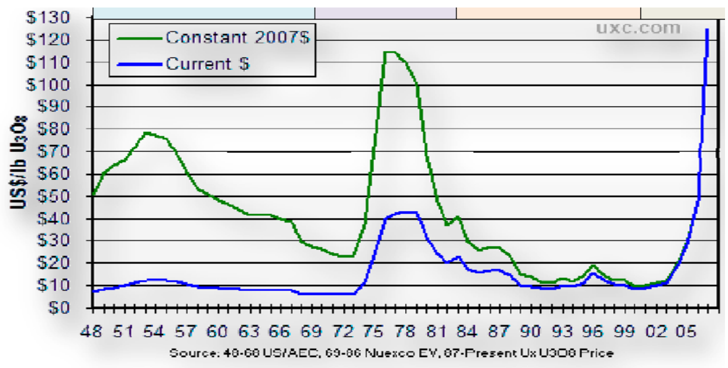

Figure 4: Historical Uranium Prices since 1948. Source: www.ux.com

The second period started after civil nuclear reactors started going online in the late 60s. During this phase, projections for nuclear power were very optimistic. In 1975, it was estimated that there would be 2000 GWe of installed nuclear capacity by the year 2000 [7]. Comparing this with the numbers from Figure 2, we see that in 2009 the installed capacity is less than 20% of that estimate. A somewhat frantic market ensued and stockpile purchases took place, leading to very steep price increases.

A partial core meltdown at the Three Mile Island NPP in 1979 and the nuclear disaster in Chernobyl in 1986 marked the sudden end of this period. It became clear that actual nuclear reactor construction would not live up to the projections. Governments and private companies started reducing their stockpiles. So called *secondary sources* of uranium also started becoming significant. This term refers to uranium from reprocessing of spent fuel or from the decommissioning of nuclear weapons. As a result, the production of primary uranium (uranium coming directly from a mine) dropped sharply. Likewise, the investment in new exploration projects decreased significantly as mine development was simply not worthwhile at such low market prices.

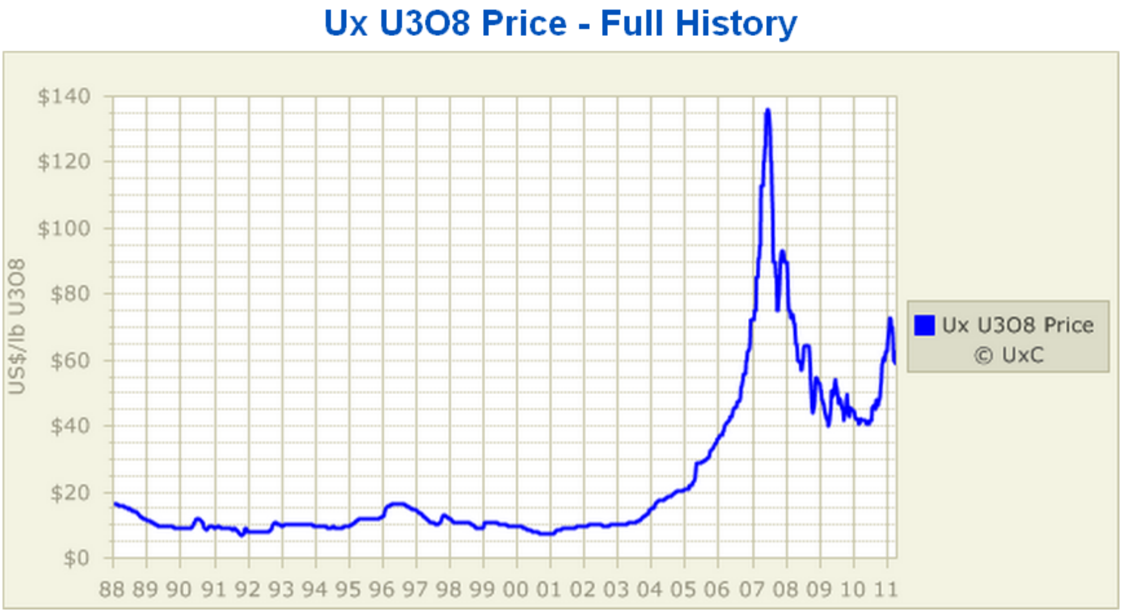

Figure 5: Uranium Oxide Spot Price by UxC. Source: www.ux.com

In 2003 a number of accidents caused temporary shut-downs of some major uranium mines. In terms of the model developed in Section 2.1 the shut-down of a mine can be seen as a removal of one of the plateaus from the merit order curve. The rest of curve is shifted to the left, leading to an increase in the clearing price. However, the extreme rise from around 10 USD/lb in 2003 to 135 USD/lb in 2007 (c.f. Figure 5) cannot be explained by this alone. At least three other factors can be identified that also played a significant role in creating this spike.

Firstly, there was psychological pressure on uranium prices due to the idea, that nuclear power is a vital part of a low CO_2 energy strategy, gaining momentum. Global political support for the construction of new nuclear power plants started growing. Secondly, market players started realizing that the cheap supply of uranium from decommissioned nuclear weapons would not be available indefinitely. There was a justified fear that, due to the long development times of mines, it might not be possible to ramp production of primary uranium up quickly enough. Lastly, speculators started showing interest in the uranium market in 2005 with hedge funds starting to operate on the spot market [5].

This overview of the history of uranium prices has clearly shown that the simple price formation model shown in chapter 2.3 has significant limitations. Factors such as the ”psychology” of the market, the existence of stockpiles, and long delay periods between the beginning of exploration and the actual commissioning of a new mine, all have an effect on uranium prices that cannot be described simply in terms of production costs and uranium demand.

3 The Uranium Market in the Aftermath of Fukushima

While chapters 1 and 2 provided a general introduction to the uranium market, this final chapter will focus on the effects of the recent events in Fukushima and on possible scenarios for the future of the uranium market.

3.1 Global Political Reactions to Fukushima

Not long after news of the terrible accident at Fukushima Dai-Ichi transpired, the global public demanded comments about nuclear safety from their political leaders. This section will provide an overview of the most significant developments.

Asia

Japan itself depends heavily on nuclear power, which contributes around 25% to its overall electricity production. It is the country with the third largest number of nuclear reactors (after the USA and France) and will thus be very hard-pressed to find substitutes in the short run, especially since it does not have the option of importing electricity. It is clear by now that the reactors at Fukushima Dai-Ichi will be decommissioned, leading to a combined capacity reduction of 4.7 GWe [8]. Furthermore, the completion of 2 nuclear reactors that are currently under construction [9] might be delayed.

Political reactions from China, Russia, South Korea and India all indicate that these countries will not abandon their ambitious nuclear energy goals. As of 1st April 2011 these countries have 27, 10, 5 and 5 new nuclear reactors under construction, respectively [9]. China's reaction is particularly important since in addition to the reactors that are currently under construction, another 50 are firmly planned. Its aim is to reach a nuclear electricity generation capacity of 400 GWe by 2050. If one puts this into perspective to its current capacity (just over 10 GWe) or that of the United States (roughly 100 GWe) [9], the crucial role that China plays for the future of the nuclear energy industry and the uranium market becomes clear.

Europe

The general reaction from Europe was that countries ordered safety reviews of their nuclear power programs. With the exception of Germany, however, no radical consequences were announced.

Germany's announcement that a previously negotiated life-time extension of its nuclear power plants would immediately be subject to a moratorium for 3 months, and its decision to shut down 7 of 17 reactors pending safety reviews, can be considered the most radical global political reaction. Public perception of nuclear power in Germany is very negative, evidenced by the fact that anti-nuclear parties have had the upper hand in recent state-elections. In view of this, it is quite likely that Germany's exit from nuclear power will progress at a significantly faster pace as the result of Fukushima.

Italy is reconsidering a re-entry into nuclear power which it abandoned in the wake of Chernobyl. The government has said that the events at Fukushima would not change these plans but a public referendum on this issue is schedule for June this year. In Switzerland the authorisation process for new nuclear power plants was frozen and safety reviews were initiated. Even though Switzerland relies on nuclear power for 40% of its electricity, with public sentiment turning against nuclear, the long-term prospects of nuclear power in a country that practices direct democracy are far from certain.

Americas

The United States government has not made any statements indicating a reversal of its decision to expand its nuclear electricity generating capacity. There is currently one reactor under construction and 9 are firmly planned[9]. Canada has 2 reactors under construction and 3 in planning and has also said that it will hold on to these plans.

In South America, Venezuela decided on halting its entry into nuclear power. Brazil has not announced any changes to its plan of adding 5 more nuclear reactors to the 2 it is currently operating. [10][11]

3.2 Immediate Market Reactions

On Monday 14th of March, the first business day after the accident at Fukushima Dai-Ichi, the market reacted with a significant price drop. The UxC weekly price index experienced its biggest single-week drop since the financial crisis in 2008 [12]. As can be seen from Figure 6, however, the news from Fukushima hit the market at a time when it had significant upward pressure. According to analysts from UxC the impact on the price could have been much more severe if the market had been under downward pressure, going as far as saying that one could have seen a "full capitulation".

Figure 6 also shows that spot prices have continuously fallen since the disaster but are still significantly above the level of mid 2010. The prices for long-term uranium contracts, indicated by the dashed line, have also fallen since March 12th but at a much slower rate compared to the spot price (solid line).

3.3 Medium and Long Term Impacts of Fukushima

The nuclear accident at the Fukushima Dai-Ichi NPP occurred during a period that has been referred to as the Nuclear Renaissance. Starting from the beginning of the millennia, many governments around the world began

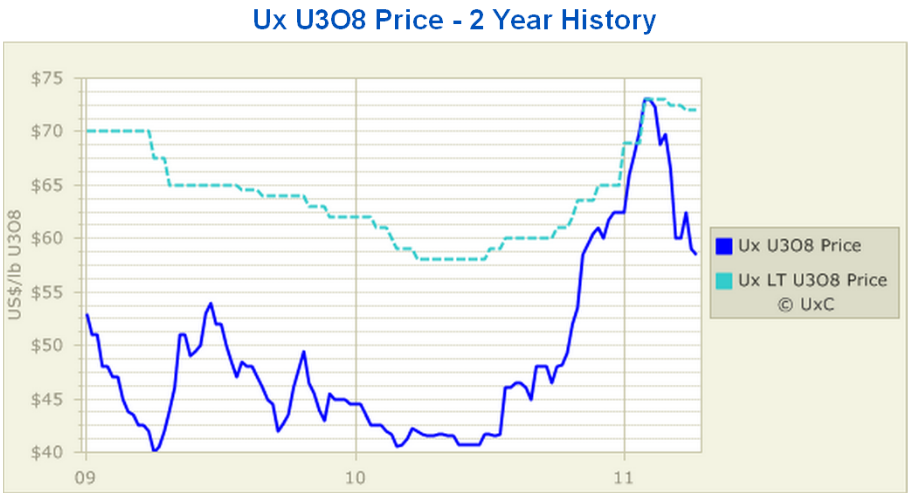

Figure 6: Uranium Oxide Spot and Long Term Price by UxC (www.ux.com)

adopting the view that nuclear energy is an important part of a strategy in the fight against global warming, and thus started paving the way for the construction of new NPPs. Together with developments described in Section 2.3, this lead to a sharp increase in uranium prices, which in return acted as a signal for increased investment in exploration and mine development (c.f. Figure 7).

As was mentioned previously, mine development is a lengthy process and the increases in investment that we see in Figure 7 might not yet have resulted in significant increase in uranium production capacities today. The upwards pressure on prices just prior to Fukushima is another indicator that supply was perhaps not yet keeping up with demand. The investments between 2004 and today (c.f. Figure 7) are likely to lead to more supply in the years to come, which would have the effect of easing high uranium prices. So Fukushima can be seen as the reason for a premature easing of the price.

It is interesting to note that even if prices were to keep decreasing at the post Fukushima rate, they would only reach pre-2003 levels in about 2 years (c.f. Figure 5). It can therefore be assumed that the short and medium-term prices still provide a high enough incentive for mine exploration and development to continue, albeit not at the rate seen in 2007. However, it can still be assumed that over the course of the next few years, new mines will be ready to produce uranium.

If during this same time period demand falls significantly (e.g. due to a shut-down of all of Germany's 17 NPPs over the next year), the short-term downward pressure due to Fukushima might turn into a medium-term price slump.

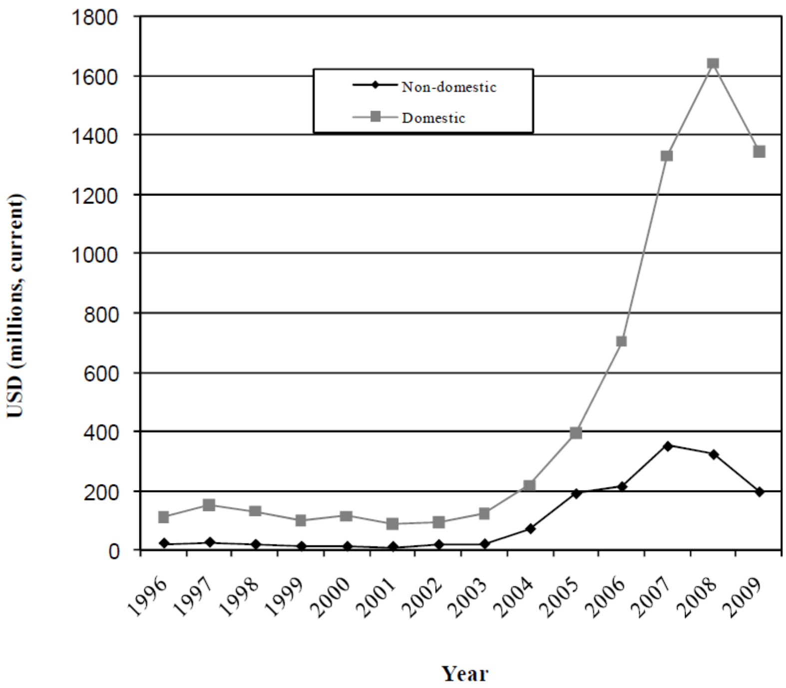

Figure 7: Trends in exploration and development expenditures. Source: [4]

In the long-term, however, Germany's potential decrease in demand will be outweighed by increased uranium requirements from countries such as China, Russia, South Korea, India, USA and Canada. Depending on the rate at which existing nuclear power plants will be decommissioned, the long-term uranium requirements of new nuclear power plants are likely to stabilise the price and keep it above a level that is sufficient for mines to produce.

As uranium from secondary sources is running out, and sources of cheap uranium get used up, the very long-term trend (20-30 years) should be pointing upwards, provided the countries mentioned above keep pursuing their targets. As was mentioned in Chapter 2.3, the impact of uranium prices on the levelised cost of electricity from nuclear power plants is very low—the nuclear industry could support significantly higher uranium prices!

The analysis provided here is highly simplified. There are many other factors that could affect the medium and long-term price of uranium. The development of a fuel-cycle based on Thorium (another naturally occurring radioactive element) could, for example, lead to a partial substitution of uranium. New reactor technologies or increased fuel reprocessing could furthermore lead to uranium being used more efficiently, i.e. more electricity extraction per kg of uranium. All of these scenarios would likely result in the demand for, and price of, uranium to decrease in the long-run.

The accident at the Fukushima Dai-Ichi nuclear power plant clearly has implications for the worldwide nuclear industry, and thus the uranium market. Even though most nations that had plans of expanding nuclear power prior to Fukushima have not moved away from their ambitions, additional safety measures might add to the time and cost that it will take to realise them. Furthermore, Fukushima might lead to the introduction of rules that increase the financial burden that operating companies have to bear in the case of a nuclear accident. This could change the way investors evaluate the risks of nuclear power and could add to a slowdown.

3.4 Concluding Remarks

Fukushima is a tremendous setback for the nuclear industry and it is clear that the "Nuclear Renaissance" that was underway has been slowed down. However, the initial global political reactions indicate that a complete stop is unlikely. The future developments at Fukushima Dai-Ichi, and how the world perceives them, will play an important role. The qualitative projections given in this paper are certainly premature, and only time will reveal the full consequences of this terrible disaster.

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