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The Transport of Nuclear Materials by Sea in Northern Europe

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Disclaimer

This report provides municipalities and other concerned groups with a detailed summary of the types of nuclear fuel cycle materials that are being transported, average figures for how often they are transported and where they are being transported to and from both within and on route through Northern European Waters. It has been compiled only from information that was accessible through public outlets and freedom of information requests. It therefore may be incomplete in areas and is likely to underestimate the numbers of some shipments.

This report is produced to convey information to KIMO member municipalities and KIMO assume no responsibility for any omission or any situation that may arise as a result of using information in this report.

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Executive Summary

In the past KIMO has campaigned against individual sea shipments of nuclear fuel cycle materials, where there was a risk posed to the marine environment or coastal communities, however there has never been a complete over view of all shipments of nuclear materials. This report investigates the transport by sea of all materials used in the nuclear fuel cycle throughout Northern Europe.

It provides municipalities and interested parties with an overview of these shipments, which may be passing their coastlines or territorial waters and covers the following areas: average shipment numbers on transport routes, types of materials and risks, ports handling the cargo, companies involved in the cycle, typical quantities being transported, packaging types and examples of ships used.

The nuclear fuel cycle is the process by which uranium is converted into a suitable form for use in electricity generation and afterwards recycled or stored. Uranium is the primary fuel used in nuclear power stations, which is a source of electricity generation in 29 countries worldwide.

The nuclear fuel cycle is made up of a series of steps that convert uranium oxide into nuclear fuel before it is stored as waste. These steps occur at facilities in different countries around the world and between these steps uranium and other materials are transported, often over large distances in large quantities by sea.

These transports are of interest due to hazardous nature of the materials transported in particular uranium and other materials produced in the nuclear fuel cycle are radioactive. That is, the atoms are unstable and decay giving off tiny particles or electromagnetic waves of radiation. The radiation is harmful as it has the ability to cause changes or mutations in living tissue.

KIMO's concern is that if an accident occurred during the transport of nuclear fuel cycle materials, which resulted in a release of radioactive material, there could could a significant imapct on the environment and the health of the local communities. Even if the imapct on the environment or health is small the damage to the reputation of an area could have a devistating impact on its economy.

Largely the transport of nuclear fuel cycle materials is low profile for security reasons and also to prevent negative public attention, hence there are no publically available reference documents describing the transports between countries.

There are varying degrees of radioactivity between materials in the nuclear fuel cycle. In general terms uranium has quite a low radioactivity and is less hazardous than some radioactive elements. The front end of the cycle, from the mining of uranium up to electricity generation mostly uses uranium compounds; therefore front end materials present less of a risk to transport in radiological terms. There are other hazardous properties however such as its chemical toxicity and the criticality risk for enriched uranium materials – this is the risk of an uncontrolled nuclear reaction occurring.

The back end of the cycle includes other elements that emit higher levels of radiation, which are very dangerous. Human exposure to these radiation levels would be fatal. The transport of some back end materials is very hazardous and regulations for the transport of these are stricter.

The transport of all radioactive materials is subject to the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Materials and the International Maritime Dangerous Goods Code. These specify the arrangements to be made before transport and also the requirements for packaging. Packaging is the main mechanism for isolating radioactive cargo from the environment in the event of a transport accident unless the materials are covered by the INF Code. This arrangement means that most nuclear fuel cycle materials can be transported on general cargo or container ships.

The transport of some back end materials - irradiated fuel, HLW and plutonium are covered by the Irradiated Nuclear Fuel Code, which specifies ship requirements to transport these materials. There are three levels in the INF Code relating to the quantity of radioactivity being transported. As these levels increase there are additional ship safety requirements such as damage stability, fire protection and back up electrical power supplies. Some INF class ships are purpose built while others undergo conversion to obtain INF status.

Although there has never been a release of radioactivity from an accident involving the fuel cycle materials there have been some incidents involving ships used to transport radioactive materials, including the MV Puma taking on water on the return journey from delivering irradiated fuel to Murmansk in 2010, the Kapitan Lus colliding with a methanol tanker between Denmark and Sweden while she was carrying uranium oxide and the Mont- Louis sinking in 1984 with a cargo of uranium hexafluoride (UF_6).


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Uranium ore U_3O_8 is transported from mines in Canada, Australia, Russia Africa and Asia to conversion facilities, which in Northern Europe are the UK, France and Russia. Hamburg is a commonly used port for U_3O_8 to pass through and the quantities of U_3O_8 being transported are on average the largest of front end materials.

After conversion to UF_6 the uranium is shipped to be enriched in fissile ^{235}U, an isotope (or form of uranium) that splits to yield energy during a nuclear reaction. The USA exports UF_6 to European countries for enrichment and the UK has also exported UF_6 to the USA. Shipment numbers are generally low (less than five a year between two destinations) and the quantities being transported are less than for U_3O_8 but higher than other front end materials. As with all front end materials radioactivity levels are low, however UF_6 is more reactive than U_3O_8 although both have toxic effects if inhaled.

From enrichment UF_6 is transported to be fabricated into pellets then fuel assemblies. Enrichment facilities are in the UK, France, the Netherlands, Germany and Russia which all export UF_6 through Northern European Waters for fabrication into fuel. These shipments are the most frequent of all fuel cycle materials with the busiest routes being through the English Channel to Liverpool and onto the USA – the freight ships used for transport from Europe to the USA call at Liverpool. The quantities being transported are less than prior to enrichment.

There are seven fuel fabrication facilities in Europe and which send shipments to the USA, Spain and countries in Northern Europe. The most frequent shipments are from the UK to Spain. There are also frequent shipments between European countries and the USA and also between Russia and Germany. At this stage in the fuel cycle both UO_2 and intact fuel assemblies are transported. The quantities of UO_2 and fuel assemblies being shipped are the smallest of the front end materials in weight terms but the radioactivity levels can be equivalent to a larger shipment of UF_6. Both UO_2 and fuel assemblies are stable materials with the main risk being the formation of a critical mass – an uncontrolled nuclear reaction; they are transported in packages to prevent this.

Transports from the back end of the fuel cycle include a range of materials from reprocessed uranium, depleted uranium and radioactive components of nuclear reactors going for recycling to materials considered much more hazardous, such as plutonium, MOX fuel, High Level Waste (HLW) and Irradiated fuel, which are covered by the INF Code. Irradiated fuel has been transported between the UK and Sweden and has been shipped from Japan to the UK for reprocessing. France and the UK have both returned HLW to Japan. Irradiated fuel from research reactors has also been shipped from Slovenia and Poland to Murmansk in Russia for secure storage. Irradiated fuel and HLW are very hazardous as they both have huge levels of radioactivity. MOX fuel containing plutonium from the reprocessing of irradiated fuel has been shipped between the UK, France and Japan. These shipments of INF Code materials are all less than an average of two shipments per year along each route.


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In the future there are set to be further shipments of HLW from the UK to Japan as there are around 750 canisters to be returned over the next ten years. However further shipments of MOX fuel between the two countries are unlikely following the Japanese governments plan to revaluate their use of nuclear power after the Fukushima incident. In the near future shipments in Europe are likely to remain similar, although there can always be a change in routes and numbers, even within the 5 year span of our data there has been a change in usage of some routes. In the future changes may appear in response to the opening of new enrichment facilities in the USA, changes in reprocessing patterns, construction of new reactors and decommissioning of aging ones.

KIMO campaigns for the transport of nuclear fuel cycle materials to be undertaken using the highest possible standards as an accident involving the release of radioactive materials would cause harm to the reputation, economy and natural heritage of nearby coastal communities. In addition to this, the health of a community exposed to radioactive materials could be adversely affected by radioactivity or toxicity and a release of highly radioactive back end materials would contaminate the surrounding environment.

KIMO would like to see an end to all shipments of nuclear waste and MOX fuel, as stated in KIMO Resolutions 1/96, 5/01 and 6/01. However if they do occur then they should be undertaken only using the highest available safety standards.

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EXECUTIVE SUMMARY

1. Introduction

The sea transport of nuclear fuel cycle materials is a routine occurrence as materials are shipped worldwide between nuclear fuel cycle facilities. Their transport is of interest due to their radioactivity, which varies between materials in the cycle, along with the danger that they pose. Materials with a high radioactivity are the most dangerous, with the potential to cause much damage to the environment or human health if they are not properly contained. Other materials with low levels of radioactivity pose less risk.

There are no publically available documents describing the transport of nuclear fuel cycle materials or even radioactive cargoes in general, as this particular type of sea trade is quite low profile. This review aims to provide information on transports of nuclear fuel cycle materials through Northern European Waters, covering the North East Atlantic, North Sea and Baltic Sea. When trying to find information on nuclear transport through an area of sea or past a coastline, it is difficult to find a starting point. There are occasionally shipments that are in the public domain (often due to protestors) and others mentioned by the industry news but nothing to give an overall summary.

This report will describe sea shipments of radioactive materials between all the stages of the nuclear fuel cycle through Northern European Waters including ports used, some routes and the risks associated with the various materials in the nuclear fuel cycle. It will also include typical quantities being transported, packaging for transport and examples of the types of ships used. The information will provide municipalities and other concerned groups with a detailed summary of the types of nuclear fuel cycle materials that are being transported, average figures for how often they are transported and where they are being transported to and from both within and on route through Northern European Waters.

Generally shipments of radioactive material are kept low profile. Firstly as there is some negative perception in the public towards nuclear power and the transport of associated radioactive materials attracts negative public attention if known about too widely. Secondly as highly radioactive materials could be extremely dangerous if they were to fall into the wrong hands and great care is taken to ensure the security of shipments.

Therefore even this report does not paint the complete picture but highlights only the information that we could access through public outlets and freedom of information request .It is therefore likely to underestimate the numbers of shipments in some areas.

Risks associated with transporting nuclear fuel cycle materials are that direct damage could be caused to the environment, through radioactivity and to human health through toxicity or radioactivity if exposure occurred during a shipping accident. An accident at sea or during loading or unloading of cargo is the main route by which a physical release of radioactivity could occur. Any such incident could also cause damage to the reputation of a coastal community or an area of coastline

The transport of nuclear fuel cycle materials is governed by the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material[1] . The International Maritime Dangerous Goods (IMDG) Code[2] also has requirements for carrying radioactive materials and the Irradiated Nuclear Fuel (INF) Code[3] specifies ship requirements when carrying certain types of radioactive materials.

All sea shipments occurring are required to comply with these regulations, which specify things such as packaging requirements and notifications to be made before transport occurs[1]. Carriers also have to comply with any instructions given for shipping from approval certificates[1]. To date there have been no shipping accidents involving a significant release of radioactive materials. However there have been a number of incidents with ships used for the transport of nuclear fuel cycle materials and on at least two occasions while carrying radioactive cargo including: the MV Puma taking on water on the return journey from delivering irradiated fuel to Murmansk in 2010, the Kapitan Lus colliding with a methanol tanker between Denmark and Sweden while she was carrying uranium oxide and the Mont- Louis sinking in 1984 with a cargo of uranium hexafluoride (UF_6).

The risk that a significant release of radioactive materials could occur is present and concerning. Therefore a detailed summary of transports is useful to have for concerned groups who wish to be aware of or to monitor nuclear shipments. This review collates information on sea transports through the whole of the nuclear fuel cycle and informs municipalities of shipments that may be passing their coastlines. It may also be used to help lobby against sea shipments where sufficient risks are being posed to a coastal community or coastline both currently and in the future.

2. Introduction to Nuclear Fuel cycle and radioactivity

Materials used in the nuclear fuel cycle are hazardous due to their radioactivity. This in simplest terms refers to the stability of the atoms, which the material comprises of. Materials that are radioactive contain atoms, which have unstable nuclei or centres, causing them to emit sub-nuclear (very small) particles or electromagnetic waves termed radiation. This radiation can take different forms but there are three main types; alpha, beta and gamma radiation.

The radiation emitted from unstable nuclei is ionising, that is it has the ability to cause changes or mutilations in biological tissues and can often be associated with causing cancerous growths. This is one reason why nuclear materials are hazardous; as they can cause damage to living tissue. Alpha, beta and gamma particles all have the potential to do damage to different extents due to their varying abilities to penetrate into tissue and the degree of ionisation that they cause. The risk to humans also depends on the route of exposure for example inhalation of a fine dust or contact through skin.

Radioactivity is one hazard of the materials used in the nuclear fuel cycle. Another is the property, which makes them suitable for use as fuel for nuclear reactors and again involves workings in the nuclei of atoms.
Nuclear reactors operate on the principle of splitting the atom to yield energy as doing so produces large quantities of energy.

Uranium which is primarily used as the fuel for nuclear reactors has a particular form (isotope) which is described as Fissile. This means that it can undergo nuclear fission where upon bombardment with a certain particle (a neutron), its nucleus will split. The uranium atom will form two smaller atoms, producing lots of energy and 2 or 3 neutrons. These extra neutrons then go on to split more uranium atoms in the same way producing a chain reaction. In nuclear power production the reactions are controlled by using boron rods, which absorb neutrons thus preventing a runaway chain reaction. Nuclear bombs also use this principle; only they contain much higher percentages of the fissile isotope of uranium so that when this chain starts it forms an uncontrollable explosion which releases vast amounts of energy.

A hazard when storing or transporting nuclear fuel is the formation of a critical mass, which means that there is a sufficient quantity of the isotope of uranium (or plutonium which also has a fissile isotope) to produce an uncontrolled chain reaction. This is of more concern at the reprocessing and enrichment stages of the nuclear fuel cycle. An example of this type of accident was at Tokai Mura in Japan in 1999, during processing of enriched uranium. A critical mass formed giving resulting in an explosion and uncontrolled nuclear reaction, lasting about a day.

Uranium is the main material used in the nuclear fuel cycle, however after the power generation stage other radioactive elements (radionuclides) are produced and these also present hazards. Plutonium is produced during a nuclear reaction and is used in Mixed Oxide Fuel (MOX), which some countries use, so plutonium is another significant element in the nuclear fuel cycle. The nuclear fuel cycle is outlined below:

2.1 Step 1: Mining and Milling

Uranium ore is mined from deposits around the world. This can be by traditional mining methods from deep underground mines or near surface deposits where open cast mines are used. The other method used for uranium mining is the in-situ leach method where an aggressive acid, alkali or oxidising solution is pumped underground into the ore to dissolve the uranium and then pumped back up to the surface where the uranium is recovered. The solution is chosen depending on geology.

Uranium ore mined by traditional methods is crushed and ground at a mill before the uranium is extracted.
There are uranium mines spread out across the globe with some of the mining countries also operating nuclear reactors. There are many companies involved between owning and leasing mines and in the planning and operations stages of uranium mining.

The main countries where uranium mines are operating in terms of production output are Kazakhstan, Canada and Australia but Namibia, Russia, Niger, Uzbekistan and the USA also have large mines (output greater than 1000 tonnes Uranium in 2009)[4].

Kazakhstan and Australia do not have nuclear power stations operating- the uranium they produce is exported. Canada also exports uranium but also uses some as fuel for it’s own nuclear reactors.

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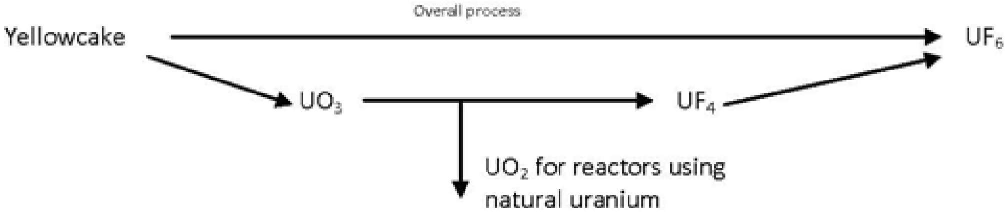
2.2 Step 2: Uranium Conversion

The next stage in the cycle of nuclear fuel is the conversion of uranium. From either method of mining the final product is called yellowcake, which is a stable oxide of uranium. It is not suitable for direct use as a fuel and requires conversion to a purer form. To make fuel for most reactors it is converted to uranium hexafluoride (UF_6), although some reactors such as the CANDU Canadian design reactors run on natural uranium (UO_2 which is not enriched).

There are 7 countries around the world which have conversion facilities, although the process of conversion to UF_6 can be split into parts. Some companies operate a two-part process and have two different facilities with the intermediate product being uranium tetrafluoride (UF_4). A further complication is that there can be a pre-conversion process of refining of the yellowcake to uranium trioxide (UO_3), which then is then is transported to be converted to UF_6.

The process can be summarised as:



The three stages that the bottom line shows are sometimes at separate facilities.

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2.3 Step 3: Uranium Enrichment

As mentioned before, the fissile isotope of uranium is the form, which can be split to yield energy upon particle bombardment with a neutron. This isotope is called ^{235}U. In natural uranium, which has been mined from the earth, the abundance of ^{235}U is about 0.7% of all uranium. The main isotope of uranium is ^{238}U, which has a natural abundance of almost 99.3%. It is not fissile like ^{235}U (although can be converted to a fissile isotope of plutonium during a chain reaction) and for a chain reaction to occur most nuclear reactors use as fuel uranium that is enriched in ^{235}U.

Most nuclear reactors that use enriched uranium require it to be enriched to between 3% and 5% ^{235}U.

There are two processes used for uranium enrichment are diffusion and centrifugation. They both require uranium in gaseous form, hence the conversion stage produces UF_6 which is easily converted to a gas.

Diffusion was the commercial process first used for enrichment on a large scale. It has now been largely replaced by the centrifugation process as only France and the USA still use diffusion on a large scale[5].

There is an enrichment plant at the AREVA Tricastin site in the South of France with a new plant being built there to replace it. There are facilities in the UK, The Netherlands and Germany operated jointly by the Urenco Enrichment Company. There is a plant in the USA, some facilities in Russia and China also has some enrichment capacity, with plans to build new facilities. There are also some small facilities in Brazil, Pakistan and Iran resulting in a total of 11 countries with enrichment capability.

2.4 Step 4: Fuel Fabrication

Once the uranium is in a form suitable to be used for fuel, the next stage is to create a fuel assembly. For most reactors this comes after enrichment; the UF_6 enriched in ^{235}U is converted to uranium oxide powder (UO_2), which is pressed into fuel pellets. For reactors that use natural uranium as a fuel, the UO_2 produced during conversion goes straight into pellets or UO_2 can be produced at the fuel fabrication facility from refined yellowcake (UO_3).


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The UO_2 pellets are then loaded into metal rods, which are sealed and grouped together to form a fuel assembly. Fuel assemblies are specific to the reactor but there are variations in shape and length between reactor types. Like all fuels, they have a defined lifetime and reactors are partially refuelled usually every 1-2 years. There are two main categories of fuel assemblies - light water and heavy water.

Fuel assemblies are manufactured at various locations around the world; there are 14 countries which have fuel fabrication facilities for Light Water Reactors (LWRs). These are the most common types of reactor used commercially for power generation. They use enriched uranium as fuel.

There are seven countries with fuel fabrication facilities for Pressurised Heavy Water Reactors (PHWRs), these are mainly the CANDU Canadian design reactors. PHWRs use natural uranium as fuel.

A newer type of fuel fabrication is the production of Mixed Oxide Fuel (MOX) assemblies for use in LWRs. These are comprised of plutonium recovered from the reprocessing of spent fuel that is combined with depleted uranium, left over from the enrichment process. The recovered plutonium oxide, of which about 65% is fissile makes up about 7% of the fuel, which is equivalent to the amount of fissile uranium in enriched fuel. Until very recently there were two facilities in Europe that can fabricate MOX assemblies; the UK and AREVA Melox in South France. The UK facility at Sellafield has now closed.

2.5 Step 5: Electricity Generation

Manufactured fuel assemblies are then transferred to reactors for power production. According to the IAEA[6], in 2010 there were 437 reactors operating worldwide in 29 different countries, which illustrates the scale of the nuclear industry. Electricity Production is the centre of the nuclear fuel cycle as it is for this reason that the cycle exists. One of the reasons for using nuclear power production is the huge quantities of energy produced. When compared to a kilogram of a coal, a kilogram of natural uranium will produce twenty thousand times the amount of energy[7]. A typical reactor used for commercial power station has an expected lifetime of 30-40 years, however some reactors in the USA are expected to be granted lifetime extensions to 60 years[8].

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2.6 Step 6: Storage of Spent Fuel and Wastes

When fuel is removed from a reactor it contains large quantities of radioactivity due to products formed from fission (splitting of the uranium atom) and other radioactive elements called transuranics (elements heavier than uranium). Transuranics are formed by reactions starting from ^{238}U capturing a neutron. This waste needs to be isolated from the environment and humans until the levels of radioactivity are safe. Spent fuel is classified as high level waste (HLW) due to its capacity for heat production in addition to the levels of radioactivity it has. Initially the spent fuel is transferred to storage ponds where it is left for a period of time, depending if it is reprocessed or not. The water in the ponds is used to cool the spent fuel and the storage ponds are shielded to isolate them. Through time the radioactivity of an element decreases. The half-life for that element is the time taken for the radioactivity to fall by half and varies greatly between different elements, from seconds to millions of years. If a country has no further use for HLW (except eventual disposal) it will be stored above ground for about 40 years, as the radioactivity levels will have fallen significantly. After 50 years radioactivity levels will have fallen by a factor of a thousand[9].

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However, some countries opt to recycle their spent fuel by reprocessing it. In this case it is removed from storage as early as five years. By doing this the volume of HLW left over is greatly reduced. HLW accounts for only 3% volume of all waste from the nuclear industry (including hospitals and industry)[9].

The rest is low level waste (LLW) 90% volume and intermediate level waste (ILW) 7% volume[9]. LLW is less hazardous in terms of radioactivity. Historically liquid wastes were often discharged into the sea; however emissions of liquid LLW have been reduced through International Conventions such as OSPAR. Solid LLW can be disposed of by near surface burial in a specially designed site. ILW needs to be stored safely as it can contain high levels of radioactivity but it is distinguished form HLW by not having the ability to produce heat. ILW can be mixed with concrete and stored in steel drums[9]. It should be noted that LLW and ILW are not just produced from the power production stage of the fuel cycle but arises from the other stages before and after it too.

2.7 Step 7: Reprocessing of Spent Fuel

Reprocessing of spent fuel can increase the energy produced from uranium and it reduces solid HLW waste volume. However it does result in additional radioactive discharges to the marine environment from the process. It involves extracting plutonium produced during power generation from spent fuel and also the uranium as there is a small quantity of ^{235}U still remaining. It leaves the fission waste products, which are vitrified (melted into a solid glass type material) and then stored for eventual disposal as HLW.

At the present time, some countries reprocess their spent fuel whereas others opt to dispose of it instead. The main reprocessing facilities are in the UK at Sellafield, La Hague in France and Mayak, central Russia.

The uranium recovered is re-enriched in ^{235}U for reuse in fresh fuel. It is however more difficult to use than natural uranium as fuel, due to the presence of other isotopes of uranium formed during fission in the initial power generation stage. These isotopes absorb neutrons and hinder the fission process meaning that reprocessed uranium needs to be slightly more enriched in $_{235}$U, before being used in fuel.

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The plutonium recovered is fabricated into MOX fuel (as described in Step 4), where fissile isotopes of plutonium produce a chain reaction. MOX fuel is used as a percentage of the whole fuel assembly, typically about 30%. There are about 30 reactors in Europe using MOX fuel; these are in Germany, France, Belgium and Switzerland. MOX fuel is also used in Japan.

2.8 Step 8: Disposal of Waste Products

The wastes which are stored, HLW & ILW are required to be further isolated until such times as their radioactivity decays to negligible levels. This will take hundreds of thousands to a million years, so something more permanent than water tanks are required.

HLW comprises of the concentrated vitrified waste fission products from reprocessing of spent fuel or the intact spent fuel rods themselves. ILW is anything which has radioactivity levels above a certain threshold and does not produce heat. It includes things such as the cladding around a fuel assembly, contaminated materials from reprocessing and other chemicals and equipment which arise from many stages of the nuclear fuel cycle. Currently all HLW and ILW is in temporary storage as it requires 40-50 years for the radioactivity levels to decay to something which is safer to handle. The technology for disposal also is still being developed. The proposed method of disposal is in underground repositories isolating the waste from the biosphere through a system of barriers.

For HLW the vitrified blocks or spent fuel rods are loaded into stainless steel or copper canisters. Both copper and steel have different properties which would help retain the radionuclides inside. The repository chamber where the canister is placed would be filled with dry bentonite clay, which swells upon wetting. This should act to prevent the penetration of water in or anything else out, for a certain period of time. The final barrier is the deep rock which surrounds the repository. It should be stable with low porosity and fractures to help retard the migration of any radionuclides which do manage to escape past the inner barriers.

ILW would be disposed of by a similar method. It is not vitrified because it does not generate heat. ILW can be stored in steel canisters after being mixed with concrete. These would be placed in a repository which does not have to be as deep underground either.

2.9 Decommissioning of Nuclear Reactors

Although not a step in the cycle of nuclear fuel, the decommissioning of reactors and other facilities for power generation can involve the transport of nuclear materials.

When a nuclear reactor reaches a point where it is not longer economically feasible to operate, electricity production will be stopped and the reactor will be shut down. After a sufficient period of time nuclear power stations and reactors can be dismantled. Other fuel cycle facilities, for example an enrichment or reprocessing plant will also have a set lifetime and once this has expired, these facilities are also decommissioned. The decommissioning of reactors is can be carried out in three different ways or a combination of them:

Immediately dismantled: Once the fuel has been removed the reactor and containment is dismantled and removed from site, allowing it to be redeveloped.

Safe Enclosure: The radioactive material is contained safely on site for sufficient time for the radioactivity to decay- this makes it less hazardous to handle. It will eventually be removed for disposal after something like 40-60 years.

Entombment: This is an option where the intention is for the radioactive material to remain on site permanently. It will be concentrated in a smaller area and then contained in a durable structure, where the radioactivity will decay to safe levels.

As the most radioactive material, spent fuel needs to be handled very carefully, 99% of radioactivity from nuclear reactors is associated with spent nuclear fuel[9]. Once this is removed from a reactor, the other contaminated materials are less radioactive and either ILW or LLW. Components of reactors, shielding or other contaminated materials are transported to storage, disposal or even recycling if either of the first two options are chosen. Transport would be mainly by land if for storage or disposal, as this is within the same country but there is also a potential for some transported by sea. A recent example of the transport of radioactive materials associated with decommissioning is the proposed shipment of steam generators from the Bruce Power Station in Ontario, Canada to Studsvik, Sweden for decontamination and recycling. In the past 40 years there have been over 80 commercial reactors and many more prototype and research reactors retired from operation[10], some of these have been decommissioned and others are undergoing it through the above three routes. This means that there is the potential for a significant amount of transport of radioactive materials associated with decommissioning.

2.10 Summary of Fuel Cycle and transport

The materials from each stage of the nuclear fuel cycle explained above are all hazardous to different extents. Between each stage radioactive materials are transported by different methods and distances. Often when over a large distance between countries, materials are transported by sea.
The front end of the nuclear fuel cycle (mining to power production) works on the basis of transporting material to be used as fuel, to be processed in the next stage of the cycle and is eventually used to produce electricity.

The back end (power production to disposal of waste products) is associated with transporting wastes to be reprocessed or stored. In terms of radioactivity, the most radioactive waste is produced during the power production stage but there are waste products produced during the front end of the cycle, which are included as LLW or ILW. Mining, Conversion and Enrichment all produce waste that must be stored or disposed of.

3. Shipping Arrangements – Safety, Regulations and Vessels

One of the original ideas with this study was to find out about the ships used to transport nuclear fuel cycle materials and their suitability. In the event of a shipping accident occurring it would appear to be very important to look at safety features of the ship, to prevent escape of cargo or exposure of the radioactive package.

To determine what ships is a difficult task as there are so many used for the transport of nuclear fuel cycle materials and they are not all recorded. The reason for this is that with much of the nuclear fuel cycle materials the features for transport safety and security are not due to the ship but instead the packaging and flasks used to contain the materials [1,11]. For all radioactive materials except those covered by the INF code, the ship used is not a particular safety feature; protection of the radioactive materials is in package design and lashings.

The international regulations specify a range of criteria that must be covered in a transport application[1]. The radioactive contents must be specified – any dangerous properties and the maximum heat produced by them[12]. The package specifications must also be given[12], namely the design features such as containment, control of radiation levels, heat damage resistance, prevention of criticality and the performance in mandatory tests of impact, fire and pressure (where appropriate). Considerable attention is also paid to the integrity of the tie down and retention systems[12]. Consignors transporting fissile materials have also to record additional information; the fissile quantity and moderator[12] (materials used to control a reaction).

Despite all these packaging requirements, there are no specific ship requirements required to carry radioactive materials mentioned in the International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Materials or the International Maritime Dangerous Goods (IMDG) Code[1,2,11]. For carrying other dangerous goods on UK vessels, there are some additional ship requirements to do with fire prevention & extinction. A compliance certificate is obtained but ships carrying radioactive materials are not required to have this[13]. The (IMDG) Code[2] has some requirements for the carriage of radioactive materials but most can be carried on board container ships, roll-on/roll-off ships or general cargo ships[14]. These of course are subject to standard inspections and requirements for regular cargo ships.

With higher risk materials, namely those covered by the Irradiated Nuclear Fuel (INF) code[3], there are however specific ship requirements. Here they are important along with package design in maintaining safety and security of the cargo. This code covers three of the nuclear fuel cycle materials which are irradiated (spent) nuclear fuel, high level waste (HLW) and plutonium (Pu)[3]. The first two are very dangerous due to the huge levels of radioactivity they contain and plutonium mainly because of the criticality risk and also proliferation as it can be used for nuclear weapons. The materials covered by the INF Code are all in the back end of the nuclear fuel cycle – transport stage 5.

In the INF Code there are three levels, each which require different additional ship safety features. Class INF 1 ships are able to carry the above materials which have a radioactivity of up to 4000 TBq[3]. Class INF 2 ships are able to carry up to 1 000 000 TBq (less for Pu) and class 3 ships are able to carry materials with an unlimited radioactivity value[3].

To carry materials in the INF Code ships must have a host of safety features which vary depending on the INF level and cover the following areas: damage stability, fire protection, temperature control of cargo spaces, structural consideration, cargo securing arrangements, electrical supplies, radiological protection equipment and management, training and shipboard emergency plans[3].
To obtain INF 1 status for some of these categories, ships have only to satisfy their government who carry out the inspection, rather than having a defined international value[15]. For INF 2 and INF 3 classifications, there are defined international standards for each of the categories with the latter being of the higher standard[15].

INF 3 ships are operated by specialist transport companies and details about these ships are available. Details of a small number of INF 2 ships were also available.

Breaking the nuclear fuel cycle into front end and back end activities, examples of shipping companies and vessels used can be described briefly. As there are no specific ship standards for the transport of nuclear fuel cycle materials (out with the INF Code), the vessel appears to be seen as being less important by the regulators. However the materials being transported can be hazardous. Are secure packaging and lashings enough to protect it?

3.1 Front End of Cycle

Mining ⇨Conversion ⇨ Enrichment ⇨Fuel ⇨Fabrication ⇨Power Generation

From the available information, the most frequently used shipping company transporting nuclear fuel cycle materials through Northern European waters is ACL, Atlantic Container Line. They are a small company of 5 large vessels which can take containers and have roll-on/roll-off capacity. UAM, Uranium Asset Management are also listed frequently as a carrier of front end materials using roll-on/roll-off ships. There is no information on the vessels themselves, as UAM do not have their own ships. There are also various other carriers listed in the data used for this study, again with little or no information on the vessels. Front end materials are carried on general cargo vessels.

3.2 Back End of Cycle

Power Generation ⇨Storage ⇨Reprocessing ⇨Recycling or Waste Storage/ Disposal

Also recycling of wastes from front end of the cycle are included

Back end materials recorded in transport which are not covered by the INF code include:

- Depleted uranium hexafluoride (UF6)
- Reprocessed uranium (stable oxide form)
- Intermediate level waste (ILW)
- Americium (separated for medical/industrial use)

Carriers used for these materials are Northern Shipping Company, ACL, and International Nuclear Services. Between them they have a mixture of general cargo and INF class ships. Occasionally INF class ships are used to carry other radioactive materials.

The other back end materials recorded in transport are all covered by the INF code including plutonium, high level waste, MOX fuel and irradiated (spent) fuel. The vessels used for their transport have to be of the appropriate INF class and are often operated by specialist companies.
International Nuclear Services (INS) specialises in spent fuel management and transports INF Code and other back end materials. They operate ships on behalf of the Nuclear Decommissioning Authority (NDA) and Pacific Nuclear Transport Limited (PNTL). The NDA ship is the Atlantic Osprey which has an INF 2 rating. PNTL have 5 ships all which are purpose built using the similar designs and all have INF 3 ratings. Most of the INF Code material transports in the data we have collected are by INS.

The safety record of transporting nuclear fuel cycle materials is good in that there has never been an accident where radioactive materials have been released into the environment. There have been a number of incidents involving the vessels which are known to transport nuclear fuel cycle materials including two accidents when radioactive materials were being carried.

The most recent incident was in Dec 2010 when a ship called the MV Puma suffered a leak and began taking in water to her engine room. A Norwegian coastguard vessel carrying a special magnetic seal came to the Puma's assistance. This happened off the coast of Norway on the return voyage from Murmansk – where the Puma was delivering irradiated fuel from a Serbian research reactor[16]. If the leak had occurred when the irradiated fuel was on board it would have been a very serious incident.

In July 2009 the Russian ship Kapitan Lus collided with a Norwegian freight ship carrying methanol, near the Oresund Bridge between Denmark and Sweden. The Kapitan Lus was carrying uranium oxide when this accident occurred and she was holed below the waterline but there was no release of radioactive material[17].

In 2008, the INF 2 vessel MCL trader ran aground near the Danish Island of Bornholm on her way from Sweden to St. Petersburg. It was not carrying radioactive cargo at the time[18].

In 2002 the INF 2 Class Atlantic Osprey had an engine room fire while leaving the Manchester Ship Canal for Sea Trials[19].
The most serious incident to occur was in 1984, where the Mont-Louis collided with a car ferry, 10 miles off the Belgian Coast while carrying uranium hexafluoride (UF_6). The hole produced during the collision caused the vessel to sink. All containers containing (UF_6) were recovered without a release occurring[20].

These incidents show that despite never being a significant release of radioactive materials during transport there have been some close encounters. When the transport of nuclear materials is necessary, we prefer that they occur on ships with the best safety features but this does not mean that the risk is eliminated. Even the most sophisticated of ships can encounter problems.

4. Quantities being transported - average for each stage of fuel cycle

Also important to know when considering the transport of nuclear fuel cycle materials, especially when deeming the transport as posing a risk, is the quantities being transported.

However quantities of material being transported cannot be used alone; as a small quantity of HLW would still be much more dangerous than 10 times the amount of U_30_8. The way in which quantities transported are recorded in this data is by weight, so by knowing this and the type of material being transported the risk from a particular shipment can be assessed.

Weight, volume or even numbers of containers of a specific size can be used to measure a quantity but as nuclear fuel cycle materials are radioactive, the total radioactivity of the materials being transported is a very useful measurement as it also gives an idea of risk. The type of material (specific radionuclides giving rise to the radioactivity) would also be required to fully determine the risk posed. Unfortunately quantities are not available for the UK recorded data but some of the other data does include quantities. Generally large quantities of front end fuel cycle materials are shipped this is more cost effective and large quantities are needed for processing, with back end materials variable quantities are transported.

From the available information on quantities being transported, it could be assumed that shipments recorded in UK data, will be similar in size. This can also be confirmed by shipments in UK data which are also listed in Hamburg data, where quantities are being recorded. Typical quantities calculated for materials from each stage of the nuclear fuel cycle are given in Section 6. These are to the best of our knowledge from the available data and cannot be taken to represent all shipments. The quantities recorded in the data collected for this study are mostly in the form of weights but radioactivity values are sometimes also recorded.

Radioactivity is measured in Becquerels (Bq). This refers to the number of disintegrations per second. A disintegration is a radioactive decay where an unstable nucleus emits radiation. Quantities of radioactivity recorded in transport lists are in GBq where there are billions of unstable nuclei decaying per second.
Becquerels are a measure of the activity of a radioactivity substance and 1 Bq is a very small unit; a typical human adult would emit about 7000 Bq from natural sources in the body and a household smoke detector would emit around 30 000Bq[21].

A shipment with a radioactivity of billions of bequerels is a much higher activity, representing the whole quantity being transported. Exposure to a small quantity of some form of front end uranium would be less but still a significant quantity.

Human exposure to radiation (dose received) is measured in a different unit the Sievert, which corresponds to a quantity of energy from radiation deposited on a mass of tissue, with a factor accounting for the type of radiation exposed to. The safe limits for human exposure are measured in Sieverts. One Sievert is a large unit and the average background dose to members of the public from natural sources is 0.002 Sieverts per year[21]. All our quantities are in Bequerels, which are not a measure of dose, but generally, higher activity materials present a greater risk.

5. Potentially harmful Properties of Uranium

This section outlines the risks associated with uranium and how they apply to its transport, as transport stages 1-4 in the fuel cycle mostly deal with uranium transport. Uranium is transported in the fuel cycle in sealed packages - our concern is that an accident could occur during sea transport or in the loading of cargoes where the packaging is breached resulting in the physical release of radioactive material. If uranium was released into the environment it could have detrimental effects on human health if taken into the body in sufficient quantities.

The two hazardous properties of uranium are its radioactivity and toxicity[22]. Uranium emits alpha radiation, which cannot penetrate skin but once inside the body can be damaging as it has the ability to cause cancer[22]. The best understanding is that every increment of radiation exposure produces an incremental increase in the risk of cancer[22].

It is also toxic to the kidneys of humans (and animals), causing damaging to the proximal tubes - the filtering component of the kidney[23]. This affects the ability of the kidneys to function properly. It is somewhat reversible as the damage caused can be repaired at lower levels of exposure. At the other end of the scale, a very high exposure could cause kidney failure and death[24].

Uranium is therefore most hazardous if it enters the body, the main routes for exposure are ingestion and inhalation but it can also enter through breaks in the skin[22], although the most likely route of internal exposure is inhalation[25]. External exposure to large quantities of uranium can also be hazardous in terms of exposure to radioactivity[22]. As well as being an alpha emitter, uranium naturally decays to other radionuclides. The decay of these products emits beta radiation, so with large quantities of uranium this contributes to the risk of external exposure[25,26]. Exposure to uranium is however regulated with a primary focus on its chemical hazard that is toxicity[22] - the radioactivity of natural uranium is low[25].

Some research has also shown uranium to have reproductive and neurotoxic effects on animals and there are suggestions that it can affect the development of the skeleton in a foetus[22].

It is also mentioned that there are socio-economic risks which could be associated with the transport of nuclear fuel cycle materials[27]. This is loss of economic or social well being, as the good image of an area could be affected. In the event of any transport accident, these risks would become much more serious and could impact on tourism and house prices[27].

Also in the event of any shipping accident involving a sinking, the difficulty of recovery of any radioactive cargo would vary depending on the sea depth[28]. A sinking vessel can also be damaged on impact with the seabed[28] this could also have implications on cargo recovery. It could be argued that a release of radioactive material at sea would have less of an impact than a nearshore release, in terms of the groups who would be exposed to it. However to it would be in the best interest to remove sunken cargo if possible before any release occurs.

Just as there are traces of uranium in food and water consumed by humans which does not harm us, uranium is naturally present in seawater at a concentration of 3 parts per billion (3µg/l)[25]. Marine organisms are therefore also unharmed by these quantities. It is not clear what levels of uranium in seawater would be harmful to marine organisms, such as invertebrates and fish[29]. Also in the event of a release of uranium occurring, it could be dispersed over a large area and depending on the chemical form would have varying degrees of solubility in seawater; this would mean that predicting any dose to marine organisms would be complex.

Uranium is known to be toxic to freshwater organisms, in some cases causing mortality[29]. Canadian Water Quality Guidelines, state that a short term exposure to 33µg/l of uranium could cause damage to sensitive freshwater organisms[29]. For long term exposure to uranium, the recommended limit to protect freshwater life is 15 µg/l [29]. These limits do not apply in seawater to marine organisms but do suggest that, there is the potential for adverse effects at certain concentrations. Section 6 on transport stages cycle includes specific details about the risks of transporting each type of material.

6. Transport of nuclear fuel cycle materials in Northern European Waters

As explained in Chapter 1, the Nuclear Fuel Cycle is the process by which natural uranium concentrates are transformed into reactor fuel and the waste products of power production and the fuel cycle recycled and disposed of. The facilities for different stages of the nuclear fuel cycle are located in various countries and the companies who purchase uranium products often choose different facilities to buy from and send to for the next stage of processing. Also there are transports between different subsidiaries of the same parent company as fuel cycle materials are passed between these subsidiaries.

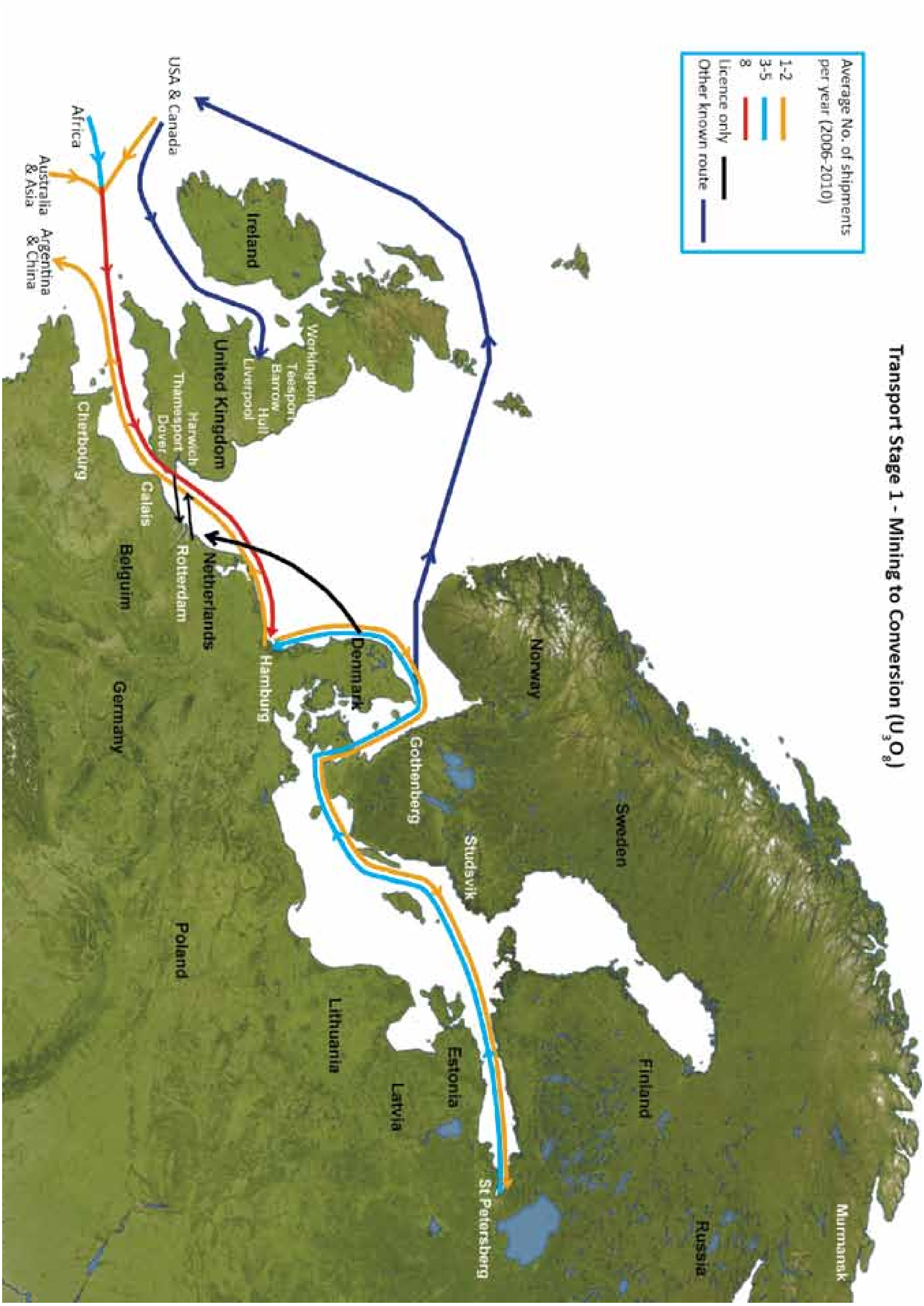
The following sections describe sea transport of nuclear fuel cycle materials between different stages of the nuclear fuel cycle. Each transport stage is described separately with information on the health risks of each type of material, quantities being transported and the types of packages used for transport. Ships types are referred to only in transport stage 5 – the back end of the fuel cycle. For transports in the front end of the cycle – transport stages 1 -4, general cargo and container ships can be used. The main transport routes between countries are then described in a table and routes are shown on a map with the average number of transports along each route per year. Routes can be direct between two ports but there are also some involving stops at intermediate ports. All routes listed are included on the maps but may not depict the exact path – we do not know such details as how close to a coastline they pass.

Numerical Data from 2006-2010 was collected from a number of different sources and compiled together. Information on these sources, along with a description of data collation and processing is given in Appendices 3 & 4. The coloured lines in each of the maps, Figures 1 to 6 represent the average number of transports per year along that route. Most of these figures given in the following sections are calculated as an average over five years. Transport Stage one is the exception where figures are a two year average, due to only two years data being available.

Data from the Netherlands from 2008 – 2010 was collected but not included in the average transport numbers as this data was a list of Dutch transport licences, not shipment numbers. However new transport routes discovered from these licences have been included in the following sections.

The transport numbers and routes listed in the following sections are as complete as we know but do not represent the absolute total. Our data was from selected sources, as not all European Countries make data on radioactive shipments through their ports publically available therefore the number of shipments on some routes may be underestimated. What is actually recorded in our calculations is the numbers of packages being transported by sea and not the number of discrete shipments or vessels each carrying a cargo of nuclear materials. However many of the listed packages are transported on separate vessels, indicated by the destinations and notification or transport dates.
In other cases two or three of the packages could be transported aboard the same vessel. Sometimes this is obvious and for others it is not possible to say whether packages are aboard separate ships. The numbers of shipments listed is then less than the number of individual vessel movements of nuclear cargo but it gives a good indication. It is not possible to count the number of discrete vessel movements so the number of packages being transported is the figure being counted and referred to throughout this report as shipments.

Figure 1



Transport Stage 1 - Mining to Conversion (U_3O_8)

Average No. of shipments per year (2006-2010)

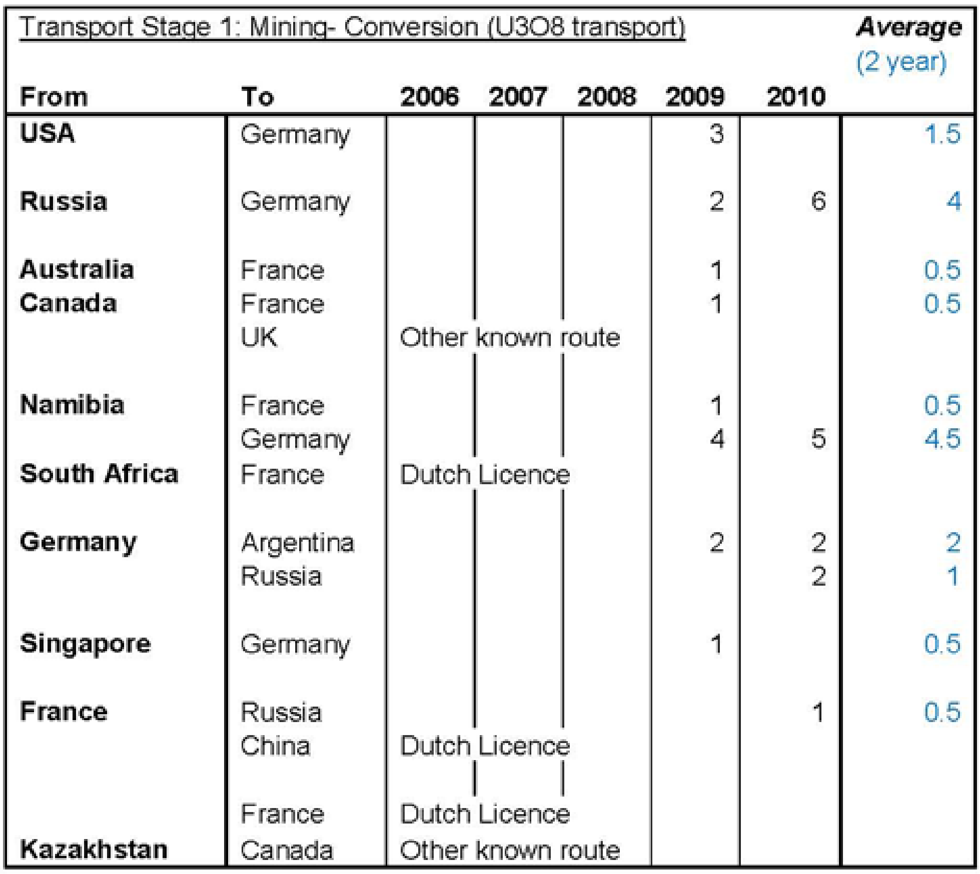
6.1 Transport Stage 1: Mining – Conversion U_30_8/ UO_3

The mining of uranium produces natural uranium ore concentrates processed into U308.

Mostly this stage involves the transport of U_30_8 but UO_3 (an intermediate product) is also transported to conversion. Both these are natural uranium concentrates with a low radioactivity and are unreactive, stable materials that are relatively insoluble in the blood[25]. If there was a release of these materials into the environment, the main risk to humans would be through inhalation of fine dusts, as a small percentage of insoluble uranium inhaled can concentrate in the lungs presenting a radiological hazard[24.25].
Natural Uranium concentrates are transported by sea using industrial packages, in large 200 litre steel drums that are built to withstand normal transport conditions only[30]. The quantities recorded as being transported are the largest of the front end materials in both weight terms and radioactivity with the average weight of U_30_8 being 316 288 kg. The average activity of the materials being shipped is 5442 GBq.

From mining of Uranium, yellowcake (U_30_8) is transported to conversion facilities. Numerical data for this transport stage is limited – only for shipments through Hamburg in 2009 and 2010, hence all lines on Figure 1 representing average numbers go to or from Hamburg. Table 1 lists the transport routes and average numbers.

Table 1



Transport Stage 1: Mining- Conversion (U3O8 transport)

From	To	2006	2007	2008	2009	2010	Average (2 year)
USA	Germany				3		1.5
Russia	Germany				2	6	4
Australia	France				1		0.5
Canada	France				1		0.5
	UK	Other known route					
Namibia	France				1		0.5
	Germany				4	5	4.5
South Africa	France	Dutch Licence					
Germany	Argentina				2	2	2
	Russia					2	1
Singapore	Germany				1		0.5
France	Russia					1	0.5
	China	Dutch Licence					
	France	Dutch Licence					
Kazakhstan	Canada	Other known route					

Figure 1 illustrates the transport routes listed in Table 1. Shipments passing through the same routes are summed together to make the map easier to read. Figure 1 also includes some routes where we do not know the numbers of shipments travelling on them. These are explained in the following section describing the main transport routes and some of the facilities where materials are shipped to.

There are two conversion facilities in Europe- Springfields Fuels Limited in the UK and AREVA in France. There are also facilities in Russia.

Canadian company Cameco operate an intermediate stage, Uranium Refining after which uranium trioxide UO_3 then goes to conversion.

Uranium in the form of yellowcake comes from many mines worldwide to the Cameco Refinery in Ontario. There is one route through Northern European waters: from Kazakhstan mines to Ontario, Canada. Sea transport is a passage through the Baltic Sea and North Sea, then into the Atlantic[31].
All uranium which is converted by Springfields, UK currently comes as UO_3 from the Cameco Blind River Refinery in Ontario, Canada. This would be transported to the UK by sea although there are no records of this in the transport data. The information comes from Springfields directly[32].
The AREVA conversion facility receives uranium in the form of yellowcake. There are occasional routes listed from Australia, Canada and Namibia exporting to France via Hamburg. Dutch transport licences also show routes from South Africa and Kazakhstan to France through Rotterdam.

There are also other more frequent exports of yellowcake listed, from Russia, the USA and Namibia to Germany. These pass through Hamburg. Although Germany is listed as the destination, it is possible these shipments of yellowcake may undergo conversion at the AREVA facility in France, as it is the nearest conversion plant. Figure 1 and Table 1 also include some other more occasional routes. These are the routes known to us through Northern European waters however there may be other additional routes that are not captured in our data.

6.2 Transport Stage 2: Conversion – Enrichment (UF_6)

The product of conversion is uranium hexafluoride (UF_6).

Uranium hexafluoride (UF_6) is quite reactive and so has a higher degree of toxicity than natural uranium concentrates[33]. It reacts with water to produce toxic HF gas[34]; this is very hazardous if inhaled. If UF_6 itself is inhaled, it quite readily dissolves in the bloodstream and more than 20% can be absorbed into the blood[23]. Of this absorbed portion around 90% is excreted and the remainder is deposited in the body (particularly the kidneys) but can also be excreted over time[25]. Another study claims that only 6% of inhaled soluble uranium will reach the kidneys[35]. For either of these figures it is when passing through the kidneys that uranium presents a toxicological hazard, however with small exposures the effects can be reversible[24].

This transport stage involves the use of special packaging, which has undergone extra tests of pressure, fire and a free drop, whereby the containers must withstand these conditions without releasing any significant quantities of radioactivity[33]. Packages are large, cylindrical steel containers of 1.25 m diameter holding up to 12.5 tonnes of UF_6[30]. From German data, the average quantity of UF_6 being shipped in terms of weight was 115 989kg though this ranged from less than 50 00kg to over 400 000kg. The average activity of UF6 being shipped was 1768 GBq. The range of activities was also large as it varies with weight – from less than 1 to over 5000 GBq.

The movements of UF_6 are widely recorded through UK ports either at this stage or in its enriched form (transport stage 3). It is often carried on vessels, which stop in the UK to load or unload other cargoes. Table 2 lists transport routes and numbers.

Table 2

Transport Stage 2: Conversion- Enrichment (unenriched UF6 transport)

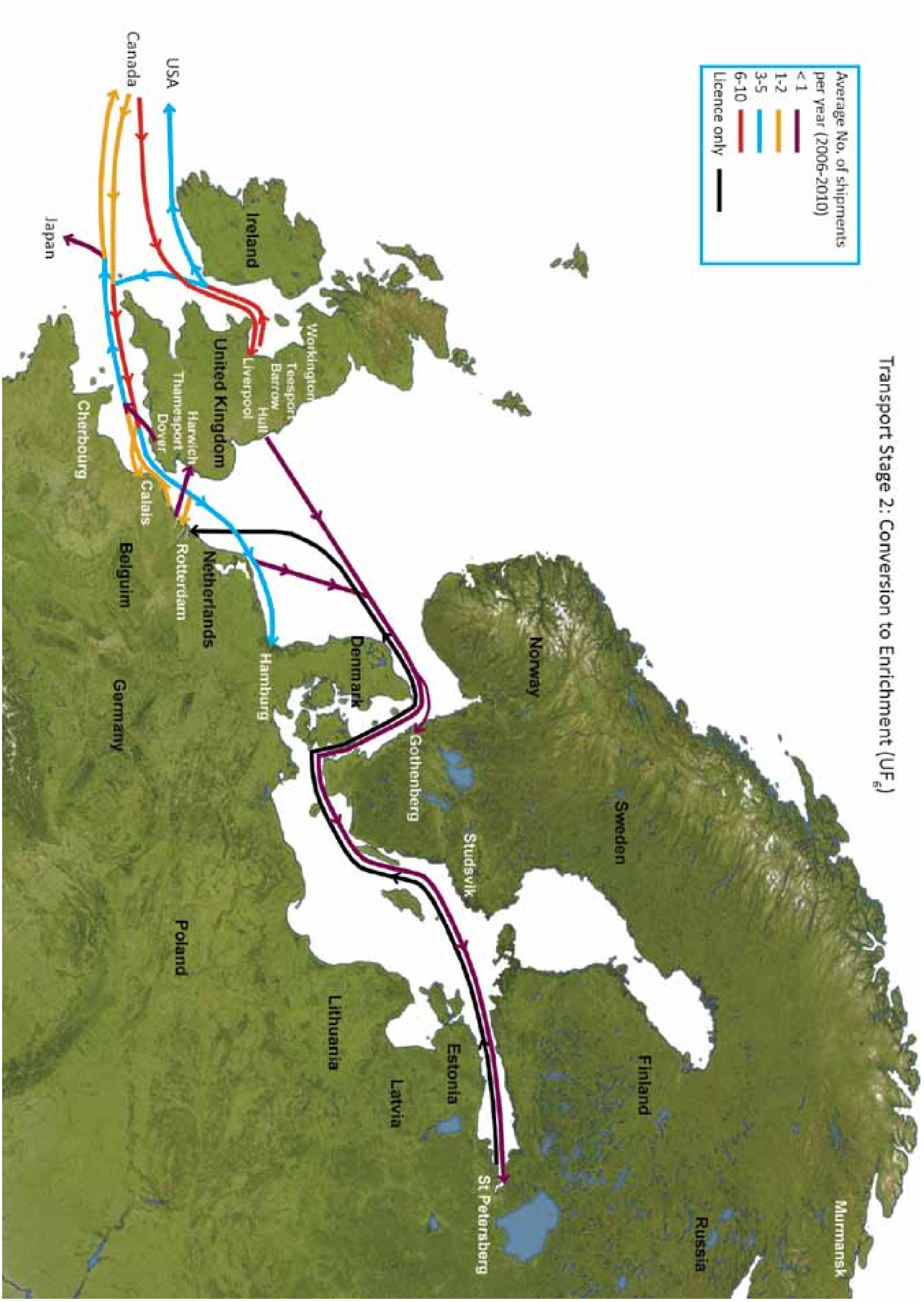
-

From	To	2006	2007	2008	2009	2010	Average
UK	USA		9	3	3		3
	Japan	2					0.4
	Sweden		1	1			0.4
	Russia			1			0.2
		2006	2007	2008	2009	2010	
USA	UK	2		12	14		5.6
	Germany				2	1	0.6
	Netherlands	1		1	6	1	1.8
	France	5				1	1.2
Russia	UK	1	1	1			0.6
	Netherlands	Dutch Licence					
Belgium	Canada				6	5	2.2
Canada	Germany				2	8	2
	Netherlands	Dutch Licence					

The transport routes of UF_6 from conversion to enrichment are illustrated in Figure 2. Shipments passing through the same routes are summed together to make the map easier to read. Although individual shipment routes which stop at an Intermediate Port are harder to follow. This short section describes the departure, intermediate and destination ports where known and within Northern Europe of the most frequent shipment routes.

- Shipments of UF_6 from Springfields Fuels (UK) to the USA are from Liverpool.
- Shipments from the USA to mainland Europe are via Liverpool, UK bound shipments are to Liverpool.
- Shipments from Techsnabexport, Russia to the UK travel by sea from Rotterdam to Harwich.
- Shipments from Canada to Germany are through Hamburg.
- Dutch transport Licences show transport routes from Russia and Canada to the Netherlands

Figure 2


Transport Stage 2: Conversion to Enrichment (UF_6)
Average No. of shipments per year (2006-2010)
<1
1-2
3-5
6-10
Licence only
Murmansk
Russia
St Petersberg
Finland
Sweden
Norway
Estonia
Latvia
Lithuania
Poland
Studsvik
Gothenberg
Denmark
Hamburg
Germany
Netherlands
Rotterdam
Belguim
Calais
Cherbourg
United Kingdom
Harwich
Thamesport
Dover
Workington
Teesport
Barrow
Hull
Liverpool
Ireland
USA
Canada
Japan

6.3 Transport Stage 3: Enrichment – Fuel Fabrication (UF_6)

The product of enrichment is enriched uranium hexafluoride (UF_6).

The particular health risks of enriched uranium hexafluoride (UF_6) are as mentioned above, primarily the toxicity if inhaled. It should be noted however, that with any form of uranium ingested or inhaled the vast majority is directly excreted without entering the kidneys[25], it is the small percentages which are absorbed into the bloodstream which has the ability to pass through the kidneys causing damage. There is also a radiological risk from internal exposure to uranium, which increases with the amount of uranium a person is exposed to. However the primary risk is considered to be toxicity.

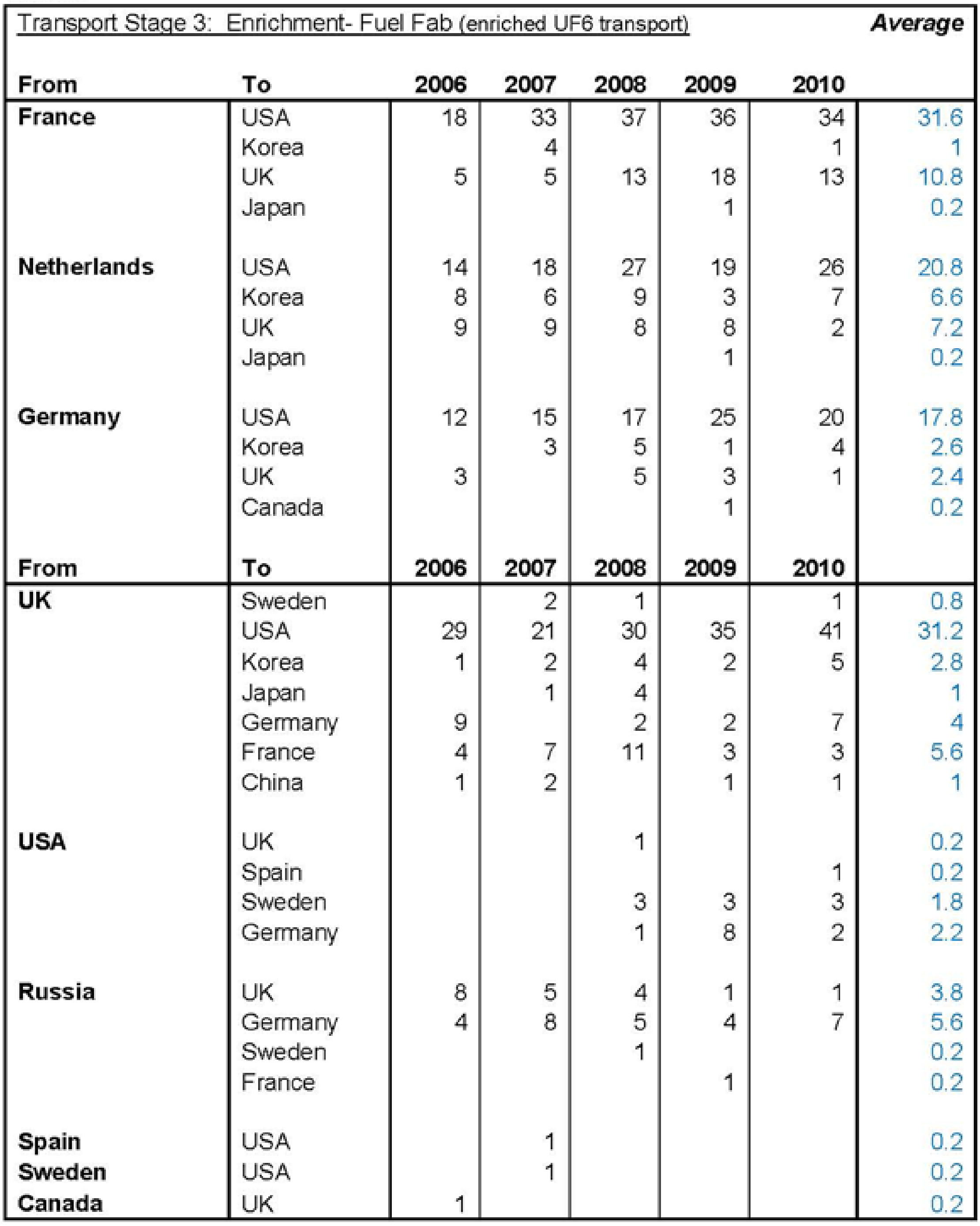
With enriched UF6, there is also the potential for a critical mass to form[30], which could result in an uncontrolled chain reaction occurring. This is as enriched UF_6 has a higher proportion of fissile ^{235}U, the isotope which makes it suitable for use as a fuel. To prevent the formation of a critical mass smaller flasks are used (76cm diameter) and these are loaded into other ISO (International Organisation for Standardisation) approved containers[30]. The flasks undergo the extra tests required for transporting UF_6. The quantities of enriched UF_6 being transported are less than prior to enrichment, with the average from our data being 81 222kg and the average activity being 1500 GBq. Dutch transport licences gave larger quantities than this, which raised the average. Shipments of enriched UF_6 through Hamburg were typically between 7000kg and 40 000kg.

Enriched UF_6 is transported to and from the UK and mainland Europe, with them both exporting to the USA and it is then ready to be made into fuel. The main exporters of enriched UF_6 are AREVA subsidiaries in France and Urenco from its three European plants (UK, Germany and the Netherlands). Techsnabexport in Russia also exports to the UK and Germany.

The transport routes of enriched UF_6 shown in table 3 are illustrated in Figure 3. This map is more complex than previous figures as there are more countries sending and receiving this material. As shown in previous figures 1 and 2, the route lines also show the number of shipments travelling along them in a particular direction. Shipments passing through the same route are summed together to keep the map as simple as possible, however this can cause difficulty when following a particular shipment route from departure country to destination, especially as many of the shipments call at intermediate ports on route. These are included in Figure 3 but for ease of following particular routes the following section is included. This section describes the most frequently routes on the Figure. Intermediate ports, the companies and facilities where the shipments are going to and from are included when in Northern European Countries. Similarly departure and destination ports are included, where known.

- Shipments of UF_6 from AREVA France and subsidiaries Eurodif and FBFC Romans to the USA transit Liverpool and to Springfields UK are from Calais to Dover.
- Shipments from Urenco Netherlands and Urenco Germany to the USA, Korea and the UK transit respectively Liverpool, Thamesport or Felixstowe and to the UK are from Rotterdam to Harwich.
- Shipments from Urenco UK to AREVA France are from Dover to Calais. Urenco UK ships to the USA, Germany and Korea respectively from Liverpool, Harwich (to Rotterdam) and Thamesport or Felixstowe.
- Shipments from the USA and to Westinghouse Sweden transit Liverpool or Hamburg. Shipments to ANF Germany are to Hamburg with no known intermediate stops on route.
- Shipments of UF_6 from Techsnabexport, Russia to the UK and Germany are from St Petersburg or (less often) Arkhangelsk to Hull and from St. Petersburg to Hamburg.

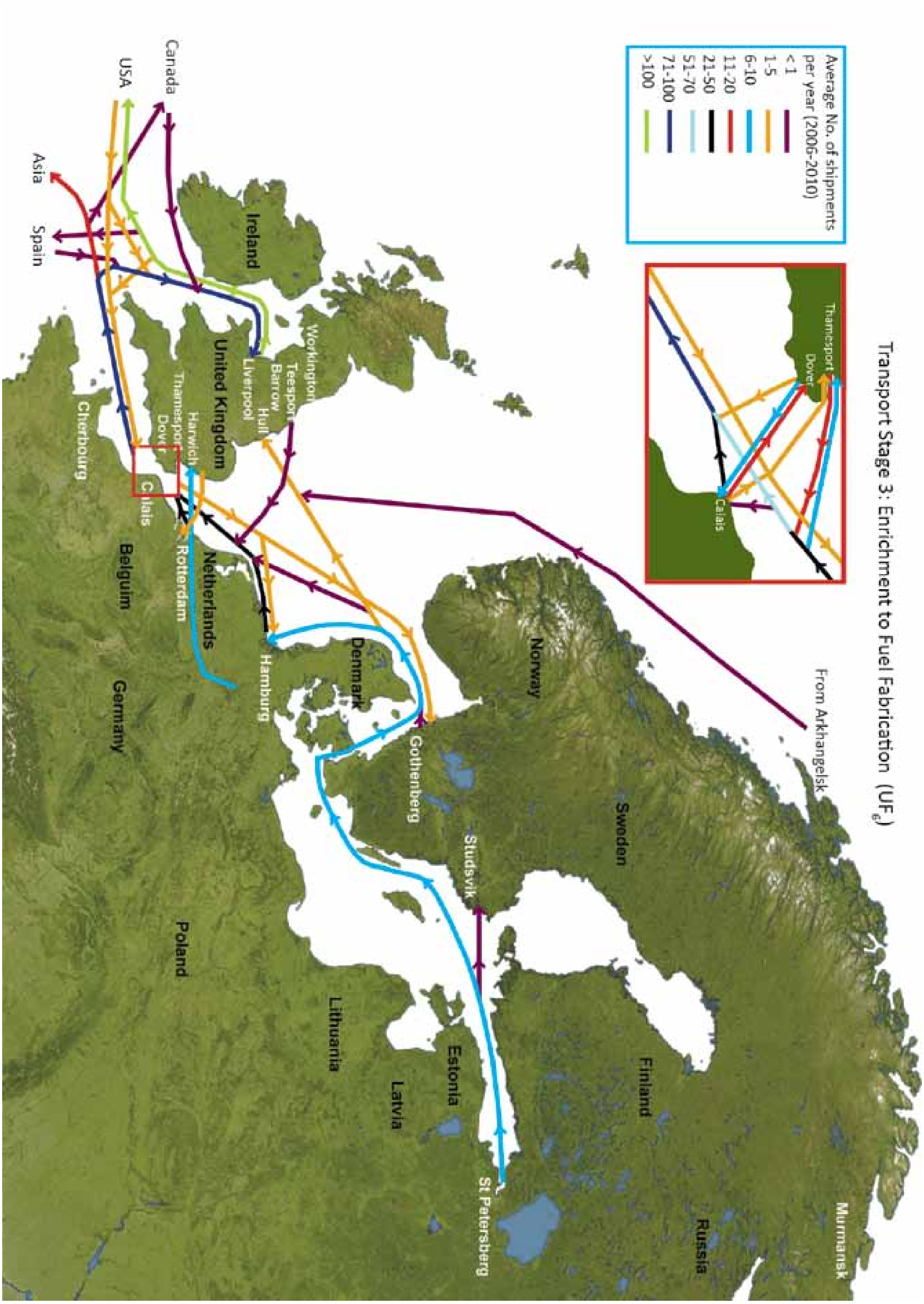
Table 3



Transport Stage 3: Enrichment- Fuel Fab (enriched UF6 transport)

From	To	2006	2007	2008	2009	2010	Average
France	USA	18	33	37	36	34	31.6
	Korea		4			1	1
	UK	5	5	13	18	13	10.8
	Japan				1		0.2
Netherlands	USA	14	18	27	19	26	20.8
	Korea	8	6	9	3	7	6.6
	UK	9	9	8	8	2	7.2
	Japan				1		0.2
Germany	USA	12	15	17	25	20	17.8
	Korea		3	5	1	4	2.6
	UK	3		5	3	1	2.4
	Canada				1		0.2
From	**To**	**2006**	**2007**	**2008**	**2009**	**2010**	
UK	Sweden		2	1		1	0.8
	USA	29	21	30	35	41	31.2
	Korea	1	2	4	2	5	2.8
	Japan		1	4			1
	Germany	9		2	2	7	4
	France	4	7	11	3	3	5.6
	China	1	2		1	1	1
USA	UK			1			0.2
	Spain					1	0.2
	Sweden			3	3	3	1.8
	Germany			1	8	2	2.2
Russia	UK	8	5	4	1	1	3.8
	Germany	4	8	5	4	7	5.6
	Sweden			1			0.2
	France				1		0.2
Spain	USA		1				0.2
Sweden	USA		1				0.2
Canada	UK	1					0.2

Figure 3



Transport Stage 3: Enrichment to Fuel Fabrication (UF$_6$)

6.4 Transport Stage 4: Fuel Fabrication - Further Fuel Fabrication – Electricity Generation (UO$_2$ /fuel assemblies)

Fuel fabrication is a three stage process:
1. Converting UF$_6$ into UO$_2$.
2. Forming fuel pellets from the UO$_2$ powder.
3. Loading pellets into rods which are grouped together to form a fuel assembly.

It often involves transport between various facilities before a fuel assembly is fabricated. Intact fuel assemblies are then shipped to nuclear reactors for power production.

The materials being transported within this stage of the fuel cycle vary from uranium dioxide (UO$_2$) powder, UO$_2$ pellets, fuel rods and complete fuel assemblies. UO$_2$ powder would present similar risks to natural uranium concentrates, in that it is relatively insoluble in the blood[25] and if fine dust was inhaled it could present a radiological hazard as small quantities could accumulate in the lungs[25]. For any of the other materials from this stage of the fuel cycle, internal exposure is very unlikely and the radiological hazard is also low[33] unless you are in close proximity to a large quantity. In the environment these materials would also be quite stable[33].

The main risk is the formation of a critical mass, which could result in an uncontrolled chain reaction[33]. This is prevented by the design of the transport containers, which separates quantities of fissile material. They are subject to accident simulation tests of submergence, impact and fire[30]. The flasks used to transport fuel assemblies are also very robust to prevent damage to the fuel assembly[30] but they do not require much radiation shielding.

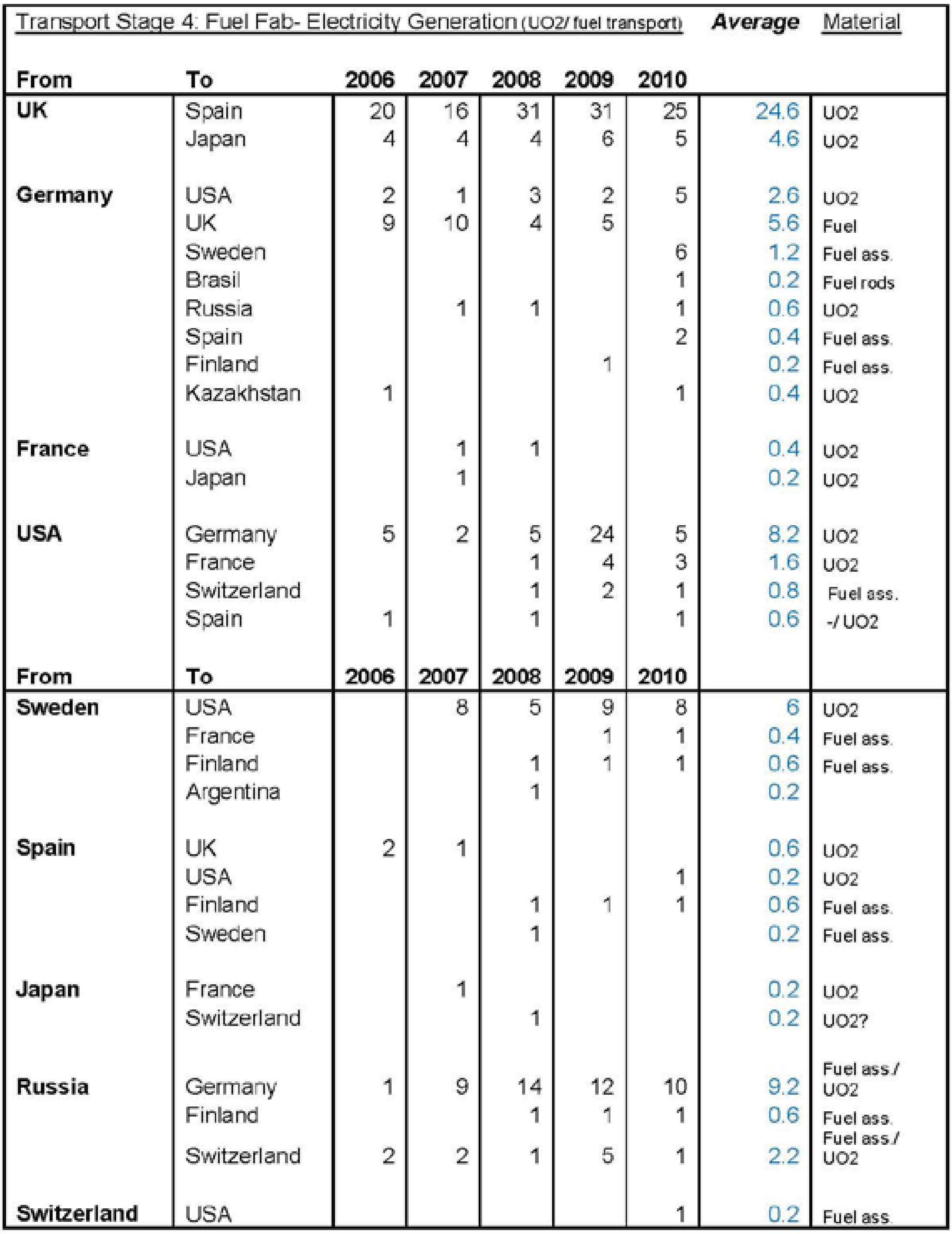
The materials recorded as being transported are UO$_2$ powders, pellets and complete fuel assemblies - mainly within Europe and to and from the USA. The quantities of UO$_2$ being transported are lesser than all of the other front end materials with the average recorded being 6389kg and the average activity was 388 GBq. The average weight of fuel assemblies being transported is around double this at 14 331kg. Some quantities were recorded in the number of fuel assemblies being transported, the average number was 110. There were very few available figures for the activity of fuel assemblies being transported; the average from this was 1959 GBq.

Table 4 lists the transport routes and numbers, as fuel assemblies and pellets both comprise of the same radioactive material UO$_2$ the transports of both are added together and the routes illustrated in Figure 4 represent the transport of both these products.

The most frequently used transport routes are described below, detailing ports and intermediate stops within Northern Europe where known:

- Shipments from Springfields UK to Spain and Japan are from Liverpool and Dover respectively.
- Shipments from ANF Germany to the USA are mostly via Liverpool and to the UK from Rotterdam to Harwich.
- Shipments from the USA to Germany sometimes transit Liverpool, others are to Hamburg with no known intermediate port calls. Shipments from the USA to France are via Liverpool.
- Shipments from Westinghouse Sweden to the USA are via Liverpool.
- Shipments from Mashinostroitelny Zavod of Russia to Germany and Switzerland are through Hamburg, likely departing from St. Petersburg.

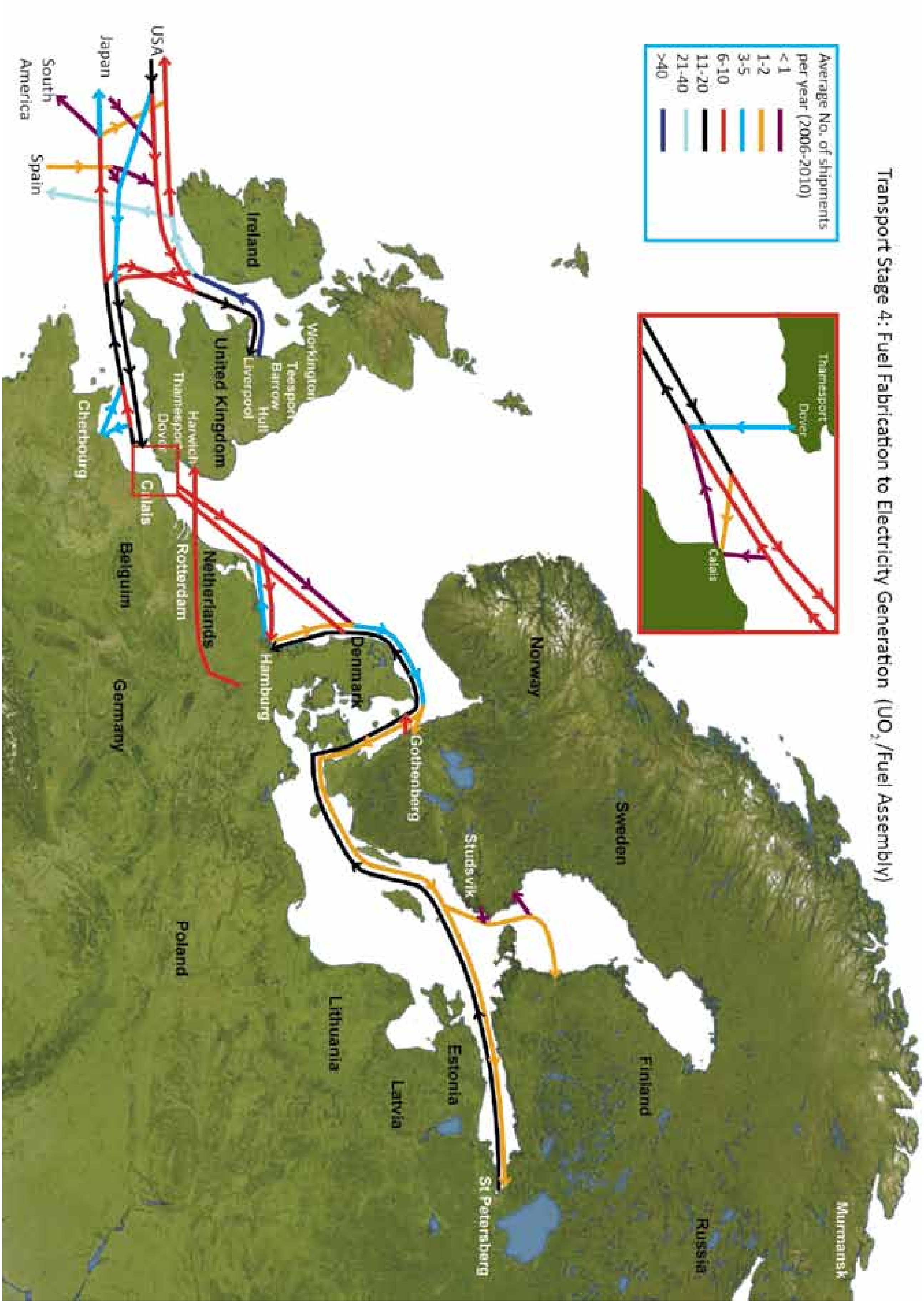
Figure 4



Transport Stage 4: Fuel Fab- Electricity Generation (UO2/ fuel transport)

From	To	2006	2007	2008	2009	2010	Average	Material
UK	Spain	20	16	31	31	25	24.6	UO2
	Japan	4	4	4	6	5	4.6	UO2
Germany	USA	2	1	3	2	5	2.6	UO2
	UK	9	10	4	5		5.6	Fuel
	Sweden					6	1.2	Fuel ass.
	Brasil					1	0.2	Fuel rods
	Russia		1	1		1	0.6	UO2
	Spain					2	0.4	Fuel ass.
	Finland				1		0.2	Fuel ass.
	Kazakhstan	1				1	0.4	UO2
France	USA		1	1			0.4	UO2
	Japan		1				0.2	UO2
USA	Germany	5	2	5	24	5	8.2	UO2
	France			1	4	3	1.6	UO2
	Switzerland			1	2	1	0.8	Fuel ass.
	Spain	1		1		1	0.6	-/UO2
From	**To**	**2006**	**2007**	**2008**	**2009**	**2010**		
Sweden	USA		8	5	9	8	6	UO2
	France				1	1	0.4	Fuel ass.
	Finland			1	1	1	0.6	Fuel ass.
	Argentina			1			0.2	
Spain	UK	2	1				0.6	UO2
	USA					1	0.2	UO2
	Finland			1	1	1	0.6	Fuel ass.
	Sweden			1			0.2	Fuel ass.
Japan	France		1				0.2	UO2
	Switzerland			1			0.2	UO2?
Russia	Germany	1	9	14	12	10	9.2	Fuel ass./ UO2
	Finland			1	1	1	0.6	Fuel ass.
	Switzerland	2	2	1	5	1	2.2	Fuel ass./ UO2
Switzerland	USA					1	0.2	Fuel ass.

Figure 4



Transport Stage 4: Fuel Fabrication to Electricity Generation (UO_2/Fuel Assembly)

Average No. of shipments per year (2006-2010)

6.5 Transport Stage 5: Back End Materials

Transports at the back end of the fuel cycle include all types of waste associated with power production for storage or reprocessing and also the transport of wastes from other stages. Although not all countries consider back-end materials are waste, uranium and plutonium from spent fuel and some other materials can be reprocessed although this does lead to increased emmissions to the marine environment. Waste materials are only transported between countries by sea for reprocessing, as storage is within the country of production.

Out of all the materials being transported in the nuclear fuel cycle, back end materials are the most diverse but also are the most dangerous, particularly due to their high radioactivity.

Irradiated (or spent) fuel contains huge levels of radioactivity due to the radionuclides produced during the fission process used to generate electricity, as does high level waste (HLW) produced from the reprocessing of irradiated fuel. These two materials are the most hazardous in the fuel cycle and before transport irradiated fuel is stored in ponds to allow some of the radioactivity to decay[9].

The transportation of these materials is in Type B casks, which are tested to withstand accident conditions and also have very thick walls to shield the radioactivity[33]. A typical cask could weigh 100 tonnes and hold around 5 tonnes of spent fuel[36]. External exposure to these levels of radioactivity as a result of an accident would be fatal. HLW is vitrified into a glass matrix which is quite stable and would not readily decay in the environment but anything around it would receive a very high dose of radioactivity.

Intermediate level waste (ILW) produced during powder generation can also be very hazardous due to radioactivity levels, as it includes materials with a wide range of radioactivity values. Low level waste (LLW) is less hazardous and less likely to be transported by sea as it is not reprocessed. ILW is sometimes reprocessed and transported by sea. For example, Sweden however transports HLW, ILW and LLW by sea to its storage facilities.

Some countries choose to reprocess irradiated fuel. In the area covered by this study the reprocessing facilities are in the UK, France and Russia. HLW waste is produced in the process as well as plutonium and uranium. Reprocessed uranium is recycled for use as fresh fuel. It can be transported in different forms but has been recorded being transported by sea from the UK as UO_3; a relatively stable oxide described in stage 1.

Plutonium (Pu) from reprocessing is either in metal or oxide form that is unreactive and generally insoluble[36] but in powder form it is easily dispersed[33]. Radioactivity levels are massively higher than that of natural uranium. This is by a factor of about eighty seven thousand for fissile ^{239}Pu [37], the most common Pu isotope formed during electricity generation. The radioactivity of plutonium is however less than that of some other fission products formed during a reaction such as strontium (^{90}Sr) and caesium (^{137}Cs) [36].

It is claimed by the industry a release into the sea would have limited effect on aquatic ecosystems[36] due to dilution however it could result in plutinium entering the human food chain. Plutonium is very toxic if it enters the body, particularly by inhalation of dust as it can be deposited in the liver and bones causing damage by alpha irradiation[38,39]. If plutonium is ingested there is a slightly lesser risk as more is excreted[38]. Toxicity is listed before radioactivity as a risk[33], however transporting plutonium also includes another serious risk which is the formation of a critical mass transport packages are placed inside a container to in such a way to prevent this[33].

MOX or mixed oxide fuel is made of both uranium and plutonium fuel pellets. The fissile material used to generate the chain reaction is plutonium. These fuel assemblies are similar to ordinary uranium fuel assemblies in that they are stable (would not easily be dispersed in the environment) and emit lower levels of radiation[34,40] . The main risk from transporting these materials is the formation of a critical mass. MOX fuel assemblies are however transported in Type B casks (high shielded and robust) [36,40].

The other back end material that is transported is depleted uranium. This is the waste left over from the enrichment of UF_6. It is termed depleted as it contains a lesser proportion of fissile uranium and is being transported for re-enrichment to be recycled back into the nuclear fuel cycle. It is often transported as UF_6 but can also be stored in a stable form such as U_30_8 and then transported for recycling[41,42]. In either case the hazards are due to toxicity rather than radioactivity. Transport casks will vary depending of the form of the depleted uranium but if transported in the form of UF_6, the casks used will be those used for UF_6 prior to enrichment[30], as the formation of a critical mass is not an issue.

The above mentioned materials are the main materials in the back end of the nuclear fuel cycle. There are also transports of materials originating in the nuclear fuel cycle which are processed into products for use in industry or medicine. These shipments are also included in this section. The risks with these materials may be different, firstly the quantities being transported will be smaller but they will still be using transport packages to the same approved standards as for nuclear fuel cycle material.

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The transport of irradiated fuel, HLW from reprocessing of spent fuel and plutonium is subject to the Irradiated Nuclear Fuel (INF) Code[3] which is a set of regulations specifying ship safety requirements. As described in Chapter three the code covers areas such as damage stability, fire safety, and electrical power supplies. There are three levels depending on the radioactivity of the materials carried and which have additional safety requirements as the maximum activity allowed increases.

Most shipments of materials covered by the INF Code in our data are by International Nuclear Services (INS) who operate two types of ship- INF 2 and INF 3. The INF Class 3 vessels are purpose built and have adittional safety features such as two independently powered engines and electrical systems and a double hull configuration to protect the cargo compartments[43]. They also carry naval guns for security. These ships are the highest specifications available and are used often on long journeys carrying INF materials. The five INF 3 ships operated by INS are quite modern as some of the older ships have been replaced. They are the Pacific Sandpiper (1985), Pacific Pintail (1987), Pacific Heron (2008), Pacific Egret (2010) and Pacific Grebe (2010)[44].

The Atlantic Osprey is the INF Class 2 ship operated by INS. She was built in 1986 and was previously a roll-on/roll-off ferry which has been converted to transport INF materials in 2001[45]. Despite being a INF 2 rating it has less safety features than purpose built INF 3 vessels - only one engine and no double hull and KIMO has campaigned against its use on shorter routes as we beilieve it is not fit for purpose.

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Other shipments of INF material in our data, using different carriers were aboard the MCL Trader and MV Puma.

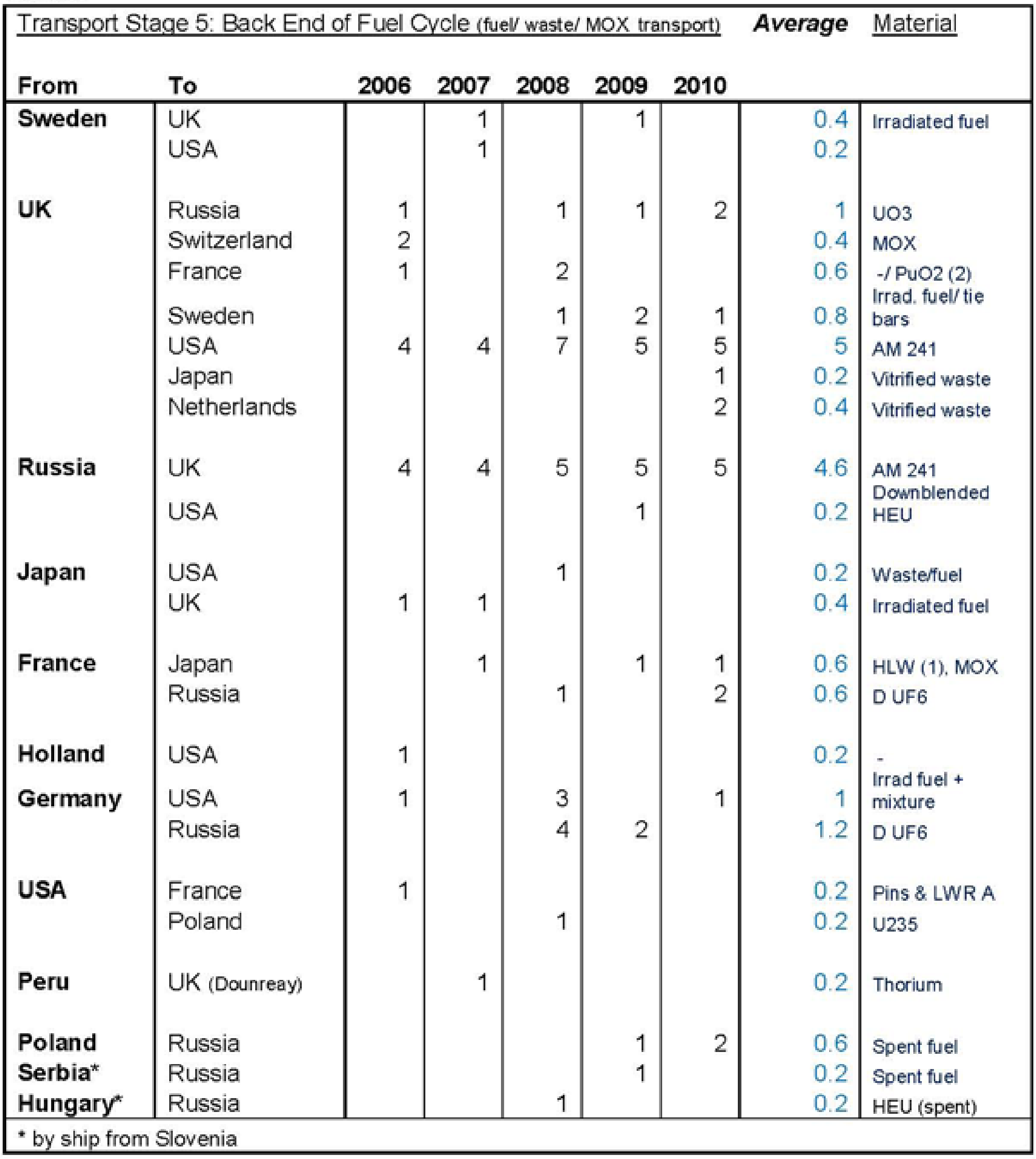
Shipments of other back end materials not covered by the INF Code are not required to be transported aboard INF class ships. The data shows that sometimes they are; there are nine shipments recorded of other materials transported using INF class ships. The other shipments are on general cargo or container ships.

Transport routes and numbers are shown in Table 5. Shipments include a variety of the materials described above from irradiated fuel and vitrified wastes to reprocessed uranium and MOX fuel, travelling within and out with Europe as imports and exports to the USA, Japan and Northern Russia.

The transport routes shown in table 5 are illustrated on Figures 5 and 6. As there are many different materials transported in the back end of the cycle, the most dangerous materials namely those covered by the INF Code, spent fuel, HLW and plutonium are shown separately as these transports are the highest risks. All other materials in the back end of the fuel cycle are grouped together and the transport numbers added. There are then four different materials shown to be transported on two maps. Figure 5 shows transports of Irradiated fuel and HLW while Figure 6 shows plutonium transports (including MOX fuel) and all other materials.

Due to the various materials being transported for different purposes transports in this transport stage of the fuel cycle are described in more detail than in the previous 3 stages. The following section lists routes, facilities and intermediate ports when in Northern Europe and also a little about the operations of some facilities. Where known the quantities and ships used are also included.

Figure 5



Transport Stage 5: Back End of Fuel Cycle (fuel/ waste/ MOX transport) **Average** Material

From	To	2006	2007	2008	2009	2010	Average	Material
Sweden	UK		1		1		0.4	Irradiated fuel
	USA		1				0.2	
UK	Russia	1		1	1	2	1	UO3
	Switzerland	2					0.4	MOX
	France	1		2			0.6	-/ PuO2 (2)
	Sweden			1	2	1	0.8	Irrad. fuel/ tie bars
	USA	4	4	7	5	5	5	AM 241
	Japan					1	0.2	Vitrified waste
	Netherlands					2	0.4	Vitrified waste
Russia	UK	4	4	5	5	5	4.6	AM 241
	USA				1		0.2	Downblended HEU
Japan	USA			1			0.2	Waste/fuel
	UK	1	1				0.4	Irradiated fuel
France	Japan		1		1	1	0.6	HLW (1), MOX
	Russia			1		2	0.6	D UF6
Holland	USA	1					0.2	-
Germany	USA	1		3		1	1	Irrad fuel + mixture
	Russia			4	2		1.2	D UF6
USA	France	1					0.2	Pins & LWR A
	Poland			1			0.2	U235
Peru	UK (Dounreay)		1				0.2	Thorium
Poland	Russia				1	2	0.6	Spent fuel
Serbia*	Russia				1		0.2	Spent fuel
Hungary*	Russia			1			0.2	HEU (spent)

* by ship from Slovenia

6.5.1 Transports shown on Figure 5: Irradiated Fuel and HLW

Studsvik, a waste treatment plant in Sweden has shipped Irradiated fuel to Sellafield UK for reprocessing. The route was Studsvik to Workington. Irradiated fuel has also been shipped from Sellafield to Studsvik, this may be a return of the reprocessed fuel. The route for these shipments is around the North of the UK to the Baltic.
There have been shipments containing Irradiated fuel from Bremerhaven, Germany to the USA calling at Wallhamn, Sweden and Workington, UK. Irradiated fuel may have left the ship at Workington for Sellafield as there are no reprocessing plants in the USA. Irradiated fuel has also been shipped from Japan to Barrow UK, going to Sellafield for reprocessing.

There have been shipments of spent highly enriched uranium fuel from Poland to Murmansk, Russia. The Russian origin spent fuel was from a Polish research reactor and was being returned to Russia, as part of the Global Threat Reduction Initiative. This initiative is seeing the return of high and low enriched uranium from research reactors around the world to secure storage, as they could potentially be used in nuclear weapons. These shipments were on the INF 2 Class, Russian vessel MCL Trader. Similarly Serbia and Hungary have returned highly enriched uranium spent fuel to Russia. The sea routes were from Slovenia to Murmansk. One of these shipments was by the Danish vessel, MV Puma, her INF Class is not known to us. The shipment from Hungary contained 155kg of highly enriched uranium in 13 transportations casks.

HLW from reprocessing at Sellafield has been shipped from Barrow, UK to Japan and the Netherlands. The reprocessing plant in France has also shipped HLW to Japan from Cherbourg. On both the routes from Barrow, quantities of HLW have been described as one flask containing 28 steel canisters. One source amounts this to 14 tonnes of HLW. The shipment from Cherbourg contained 130 steel canisters, about 4 and a half times more amounting to around 60 tonnes of HLW. The shipment from Barrow to the Netherlands was on the Atlantic Osprey, to Japan the Pacific Sandpiper was used.

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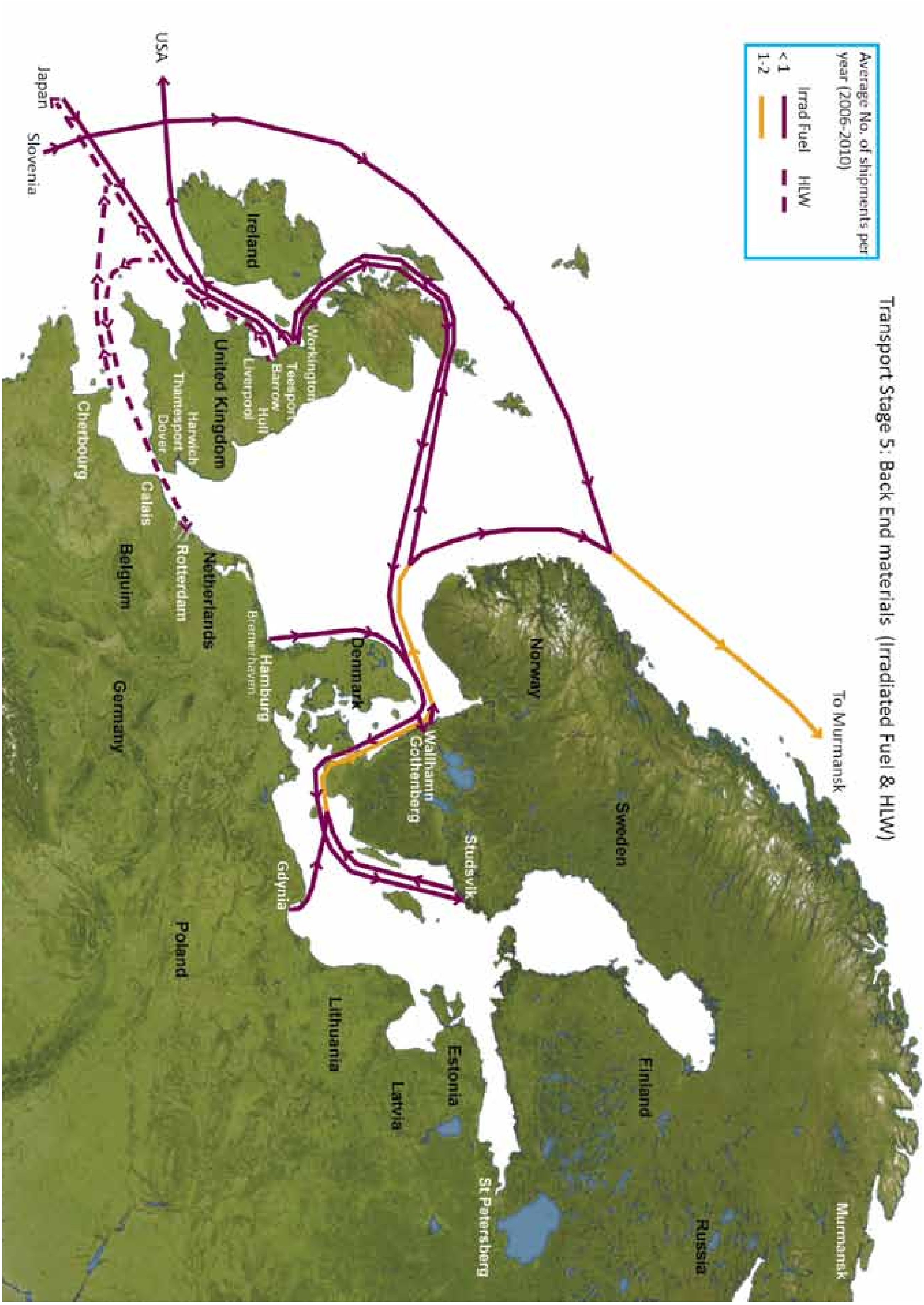
Figure 5


Transport Stage 5: Back End materials (Irradiated Fuel & HLW)
Average No. of shipments per year (2006-2010)
Irrad Fuel
HLW
< 1
1-2
USA
Japan
Slovenia
Ireland
United Kingdom
Workington
Teesport
Barrow
Hull
Liverpool
Harwich
Thamesport
Dover
Cherbourg
Calais
Belguim
Rotterdam
Netherlands
Bremerhaven
Hamburg
Denmark
Germany
Norway
Wallhamn
Gothenberg
Studsvik
Gdynia
Poland
Sweden
To Murmansk
Lithuania
Latvia
Estonia
Finland
Russia
St Petersberg
Murmansk

6.5.2 Transports shown on Figure 6: Plutonium (including MOX) and other back end materials

Plutonium oxide, a product of the reprocessing of spent fuel was shipped from Workington, UK to Cherbourg, France. This would be produced by Sellafield and fabricated into MOX fuel in at the AREVA Melox plant in France.

Sellafield until very recently also produced MOX fuel. MOX fuel for use in Switzerland was shipped by sea from Barrow, UK to Cherbourg, France. The first of these recorded shipments was 1.25 tonnes of MOX fuel containing 90kg of plutonium. The second shipment was 4 MOX fuel assemblies with no weight given. Both the shipments of plutonium oxide and MOX fuel from the UK to France were by the Atlantic Osprey. MOX fuel produced in France was shipped to Japan for use in Japanese power stations. The first of these shipments was 32 MOX fuel assemblies containing 1.8 tonnes of plutonium, the second was 12 MOX assemblies. On both these journeys, two INF 3 ships were used – the Pacific Heron and Pacific Pintail.

The transports of other back end materials are added together as they are less hazardous than the previously described INF Code materials. Selected routes are described below.

Tie bars hold together fuel elements in a complete assembly. Tie bars separated from fuel elements at the Sellafield reprocessing plant have been shipped from Workington, UK to Studsvik waste treatment plant in Sweden, again travelling around the North of Scotland.

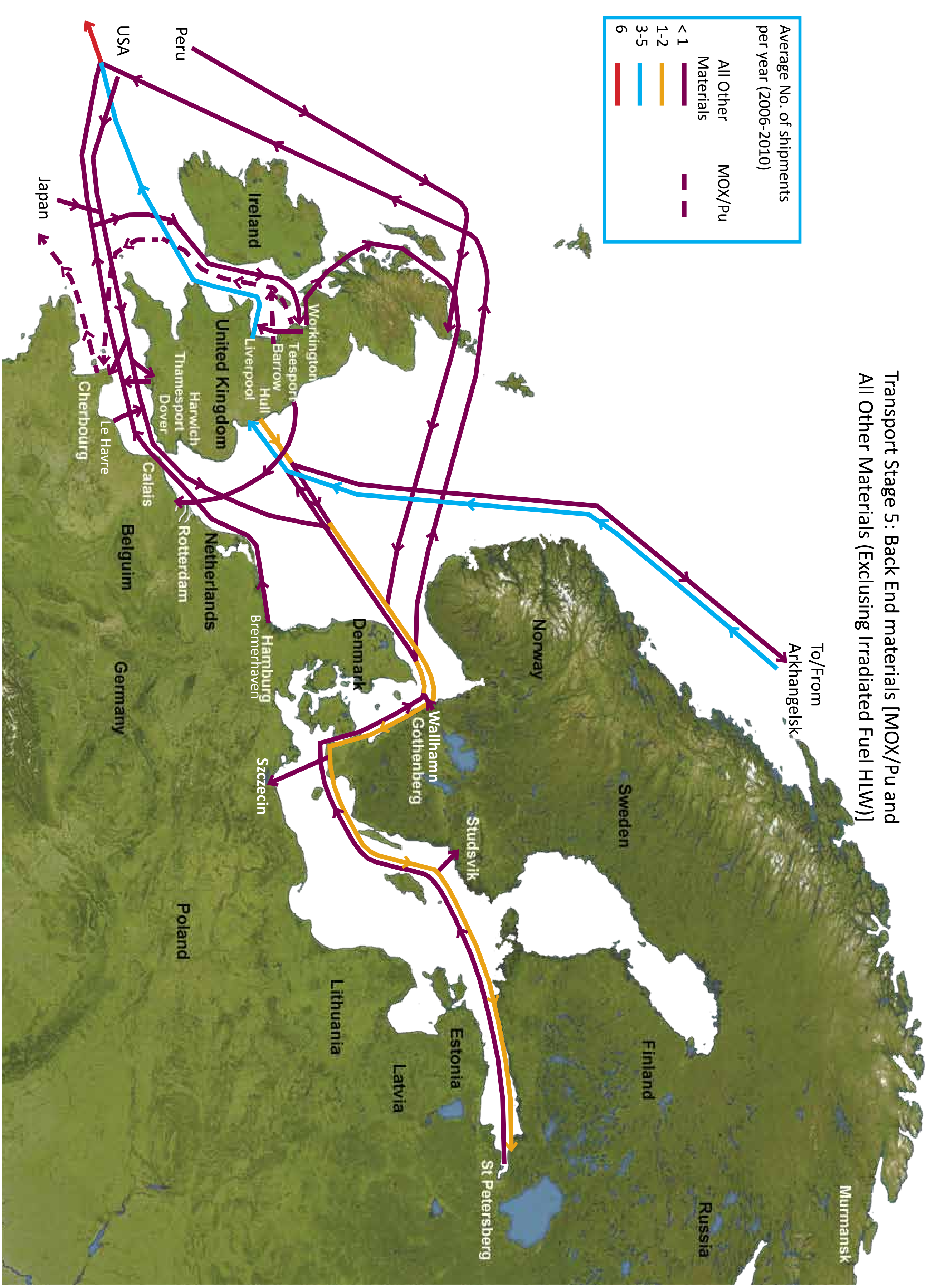
Reprocessed uranium produced at Sellafield has been shipped to annually to Mashinostroitelny Zavod, Russia from Hull to either St. Petersburg or Arkhangelsk. It is produced from the reprocessing of irradiated fuel.

FSUE Mayak (Russian reprocessing facility) transports ^{241}Am to Reviss UK from both St. Petersburg or Arkhangelsk to Hull. Reviss are a global company who manufacture or supply radiation sources for medical or industrial applications. Reviss UK transport ^{241}Am from Liverpool to the USA for use there.

Depleted Uranium is a by product of the enrichment process (step 3 of the fuel cycle). Urenco Germany has made various shipments of depleted UF_6 to St. Petersburg, Russia for reprocessing. There have also been shipments of depleted UF_6 from Le Havre France to St. Petersburg.

The shipments of depleted UF_6 from Germany were commonly on the German ship MV Shouwenbank and information from press releases states that the quantities being transported on this route were 1000 – 1250 tonnes. One shipment from France to St Petersburg was 650 tonnes. The quantities of depleted UF_6 are the largest recorded by weight in our data.

Figure 6



Transport Stage 5: Back End materials [MOX/Pu and All Other Materials (Exclusing Irradiated Fuel HLW)]

6.6 Decommissioning of Nuclear Reactors

Decommissioning is not a stage of the nuclear fuel cycle, although it involves the transport of materials which have become radioactive during power production. These materials would be classified as ILW and LLW. As mentioned before there have been many reactors retired from operation and the decommissioning process could result in the sea transport of radioactive materials for reprocessing.

In the data collected for this study, there have been no decommissioning transports recorded during the period 2006 – 2010. This is not too surprising as there was only a limited amount of data available.

There is however, the proposed shipment of 16 steam generators from Canada to Studsvik, Sweden for decontamination and recycling which is likely to occur towards the end of 2011[46]. The reduced volume of waste from this process would be shipped back to Canada and the resultant decontaminated metal sold.

This shipment is of much concern to many groups who do not want these radioactive materials being transported through their waters or past their coastline, especially as it will pass through the Great Lakes and St. Lawrence Seaway before reaching the ocean. A major concern is they will be transport under special arrangements, rather than a routine licence as the radioactivity levels exceed the regular limits for materials which are not transported in sealed containers – the steam generators are too large for this.

7. Past, Present and Future Transport Projections

7.1 Past Transport

The above figures are based on data from 2006-2010, over a five year average. Two or three years before this time front end (transport stages 1-4) routes and transport numbers are likely to have been quite similar, as the number of reactors in EU countries have not changed much during this period and many current of the fuel cycle facilities have been operating for a while. For the number of reactors in EU countries during the years since 2000, see Appendix 2.

Past back end transports are likely to have also been similar in the years before 2006. As described in chapter 6.5, there are a variety of materials being transported during this stage of the fuel cycle. Some transports recorded in the previous years are listed below to give examples of the types of transports occurring in Transport Stage 5 of the nuclear fuel cycle.

- In September 2002, Japan returned MOX fuel to Sellafield UK. It was unirradiated and returned due to concerns over its quality.
- In March 2003, spent fuel from an Italian research reactor was shipped to Sellafield UK. The sea route was from Dunkirk, France.
- In September 2004, the US shipped weapons grade plutonium to France (through Cherbourg) for conversion into MOX fuel.
- In May 2005, Sellafield UK shipped 4 MOX assemblies to Switzerland. Transport by sea was to Cherbourg France.
- In December 2005, more than 450 tonnes of depleted uranium hexafluoride was shipped by sea from Le Havre, France to St Petersburg, Russia.

The transports above from 2002 – 2005 show that during these years, the types of materials being transported in the back end of the nuclear fuel cycler are very similar to the years 2006 - 2010 used to calculate the average figures. Also the routes used are similar between the two time periods. In recent years back end transport routes and materials have been similar.

7.2 Current Transports

Some of the data collected in this study was for 2011 but it could not be used in the average calculations as it was not for a complete year. This data was studied to highlight any new transport routes not previously mentioned which are occurring now and may also be used in the future. With the exception of 1 route, all 2011 data (an incomplete year, collected from the UK and Germany) was along routes previously recorded between 2006 - 2010. The exception was the transport of fuel assemblies from Westinghouse Sweden to Switzerland, with the sea route being Sweden – Germany.

7.3 Transports through Dutch Ports

Data from the Netherlands from 2008 – 2010 was collected. It was unable to be used in the average transport figures as it was not a count of shipments but instead a list of transport licences through Dutch ports with expected maximum numbers of shipments. These were not used in the calculations as there was no way of determining how many of these actually occurred and also in what year as often licences lapsed into different years. Transport routes exclusive to the Dutch licences were listed and included on Figures 1 and 2 as potential routes for the transport of these materials.

7.4 Transports through Belgian Ports

Belgian authorities were unable to disclose detailed data but were able to provide figures for the numbers of shipments of various nuclear fuel cycle materials through Belgian Ports, each year between 2008 and 2010. These have been transformed into average figures:

Average transports through Belgian Ports per year (covers imports exports and perhaps transits)
U_30_8: 12 shipments
UF_6: 121 shipments (Includes enriched and non – enriched UF_6)
UO_2: No shipments
Fuel Elements: 19 shipments

There are no firm ideas of where these materials are going to. It is likely that fuel elements are exported as the AREVA subsidiary at Dessel manufactures fuel assemblies. U_30_8 could be imported for conversion in France and UF_6 could be both exported and imported. The shipments through Belgian ports add quite a substantial number of transports to what has already been calculated.

7.5 Transport predictions for the future

There were some differences in transports through Northern European waters through the period 2006 – 2010, which was used to calculate the average figures. During this relatively short period there were new routes appearing and older ones being used less. In future years there will be more changes, although it is likely some will remain while fuel cycle facilities remain open.

The highest average transports over the 5 year period are shipments of uranium hexafluoride (UF_6) to the USA from Europe (UK, Germany, France, and Netherlands). Currently there is one enrichment facility in the USA, so additional requirements are shipped there. By 2015 there will be another three enrichment facilities in operation[5], by AREVA, Urenco and a Laser Enrichment facility using new technology. This will increase the enrichment capacity of the USA, although the production of the current facility is predicted to decrease by 2015[5]. Overall, the USA will have a slightly higher enrichment capacity so the number of required shipments may change but this will also depend on the demand for fuel assemblies; if there are more or less reactors in operation.

Waste storage facilities are currently in the country of production of the waste[47], therefore sea shipments in the back end of the cycle to storage facilities are between countries only when there is reprocessing involved, otherwise waste shipments are within a country. In Sweden spent fuel is taken by sea to an interim storage facility at Oskarshamn, LLW and ILW is also transported by sea for storage.

In the future there could be international waste repositories, where a group of countries deposit their HLW from electricity generation[48]. Such repositories are still in discussion and there have been no sites agreed upon. Australia has been considered to have suitable geology along with South Africa, Argentina and the Middle East but no country wants to take another's HLW. If they are ever built then this may result in increased sea transport of HLW between countries adding to the number of back end transports.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As more nuclear reactors reach the end of their working lives, decommissioning operations will take place. Depending on the method chosen, this can result in the transport of some ILW and LLW for recycling. Although there were no decommissioning transports recorded in the data from 2006 – 2010, the proposed shipment of steam generators from Canada to Sweden for recycling is likely to occur in late 2011. If more reactors are decommissioned in the future there could be an increase in these types of transport.

After the reprocessing of irradiated fuel, HLW is returned to the country of production. Our data shows one shipment of HLW has returned to Japan from Sellafield UK in 2010. Since then another shipment has occurred in August 2011, departing the UK from Barrow with 76 canisters of HLW in 3 transport flasks, almost three times the amount of the first shipment in 2010. There are set to be further shipments of HLW from the UK to Japan as there are between 850 and 100 canisters to be returned which could take up to 10 years to complete[49,50].

8. Discussion

The data available for inclusion in this report shows a significant number of sea shipments of nuclear fuel cycle materials occurring. The bulk of this data is from two countries but does include many shipments destined for elsewhere. It was not possible, because of difficulties in accessing data, to ensure all shipment were included and therefore the total number of transports through Northern European Waters may be greater. Shipments of nuclear fuel cycle materials are occurring regularly and they are commonly handled at many ports.

The most common nuclear fuel cycle material to be shipped through these waters was uranium hexafluoride (UF_6). Shipments of UF_6 from European countries to the USA reached on average between 20 and 30 consignments per year from each of the four commonly exporting countries; the UK, Germany, France and the Netherlands (not all of these were on board separate ships).

The average numbers of shipments between any two destinations for other nuclear fuel cycle materials are much less. Many routes have less than 1 shipment per year - on average for that stage in the fuel cycle. For example shipments of UO_2 from Germany to Russia – transport stage 4. Others have between 1 and 5 shipments per year, for example the transport of UF_6 after conversion from the UK to the USA – transport stage 2. There are fewer routes that have between 5 and 10 shipments per year, such as the transport of enriched UF_6 from the Netherlands to Korea – transport stage 3. Routes with more than 10 shipments per year are quite rare, such as the transport of enriched UF_6 from France to the UK. These figures now seem low but there are many routes listed for each stage in the fuel cycle, and these join together at various points as shown on Figures 1 to 6.

There are also materials from different stages in the fuel cycle being transported on common routes, all happening simultaneously throughout the year. This amounts to a significant total number of shipments of nuclear fuel cycle materials occurring and certain areas in Northern European waters are particularly busy as shipments coming to and from similar destinations are following a similar route.

For example the English Channel is a busy shipping route for all types of cargo – many materials from the nuclear fuel cycle are travelling on regular cargo services so these of course follow regular shipping routes. Some back end shipments travelling on INF Class ships also use the Channel.

Between the English Channel and Liverpool is also a well used route for many fuel cycle materials along with frequent shipments coming to and from Liverpool to other areas of the world.

Shipments frequently travel between the English Channel and the Baltic Sea passing the coasts of France, Belgium, the Netherlands, Germany and Denmark on the North Sea. Often ports in these countries (excluding Denmark) are destinations where ships deliver or collect radioactive cargoes while travelling in either direction. Shipment routes extend through the Baltic Sea to St Petersburg, which is a commonly used port for fuel cycle materials.

Materials from many stages of the fuel cycle often arrive and depart from the same ports. Other popular ports used are Hamburg, Rotterdam, and Liverpool although for some back end materials Workington and Barrow are used instead of Liverpool. In France there are three ports, which we know of – Calais, Cherbourg and Le Havre are used for different fuel cycle materials and this is illustrated in Figures 2 to 6.

The materials being transported in the front end of the cycle are mostly uranium compounds and they are unirradiated. They pose a lesser risk compared to some of the back end materials, requiring less stringent shipping arrangements. Although a direct exposure to them could still be hazardous to health. If there was a release of uranium in powder form or a fire where fine particulates were dispersed into the atmosphere near people, the main health risk would be from the toxicity of inhaled uranium dust. External exposure of people to a large quantity of a front end material could also present a risk from radiation. The smaller number of routes listed for transport stage 2, conversion to enrichment, reflects that there are fewer conversion facilities, compared to enrichment or fabrication.

The quantities being transported in the front end of the cycle decrease from transport stage 1 - 4. This is to prevent the formation of a critical mass in the higher stages, where the uranium has been enriched with a higher proportion of fissile ^{235}U. The ships used to transport front end materials are general cargo or container vessels with the prime safety feature being transport packaging.

Materials from the back end of the fuel cycle contain a mixture of radionuclides and a mixture of radioactivities. HLW and Irradiated fuel are the two most hazardous materials in the whole of the nuclear fuel cycle containing elements emitting higher levels and different types of radiation than uranium. The levels of radiation emitted from HLW and irradiated fuel are very high – irradiated fuel is stored for around 5 years before it can be handled for reprocessing. They require highly shielded packaging for transport and also certain ship safety requirements, as stated in the INF Code 3. Other back end materials, such as depleted uranium, are less hazardous. Most routes listed for back end transports have an average of less than one shipment per year. These transports occur less regularly although the quantities being transported vary widely.

The class of ship with the most safety features is INF 3, which is used to transport irradiated fuel and HLW over long distances. INF 3 ships operated by INS are purpose built and have safety features such as a double hull configuration and two independently powered engines and electrical systems. INF 2 ships also carry the same cargo but have a limit for the quantities they can carry. There are specific safety requirements but these are lesser than INF 3 ships. Back end materials not included in the INF Code are able to be transported on general cargo or container vessels, again with packaging being the main safety feature.

Selected data from 2011 shows current transport routes to be following those listed above. For the near future it seems likely that transport routes and numbers will remain similar. Figure 7 shows the variation in total transport numbers from 2006 - 2010.

Figure 7

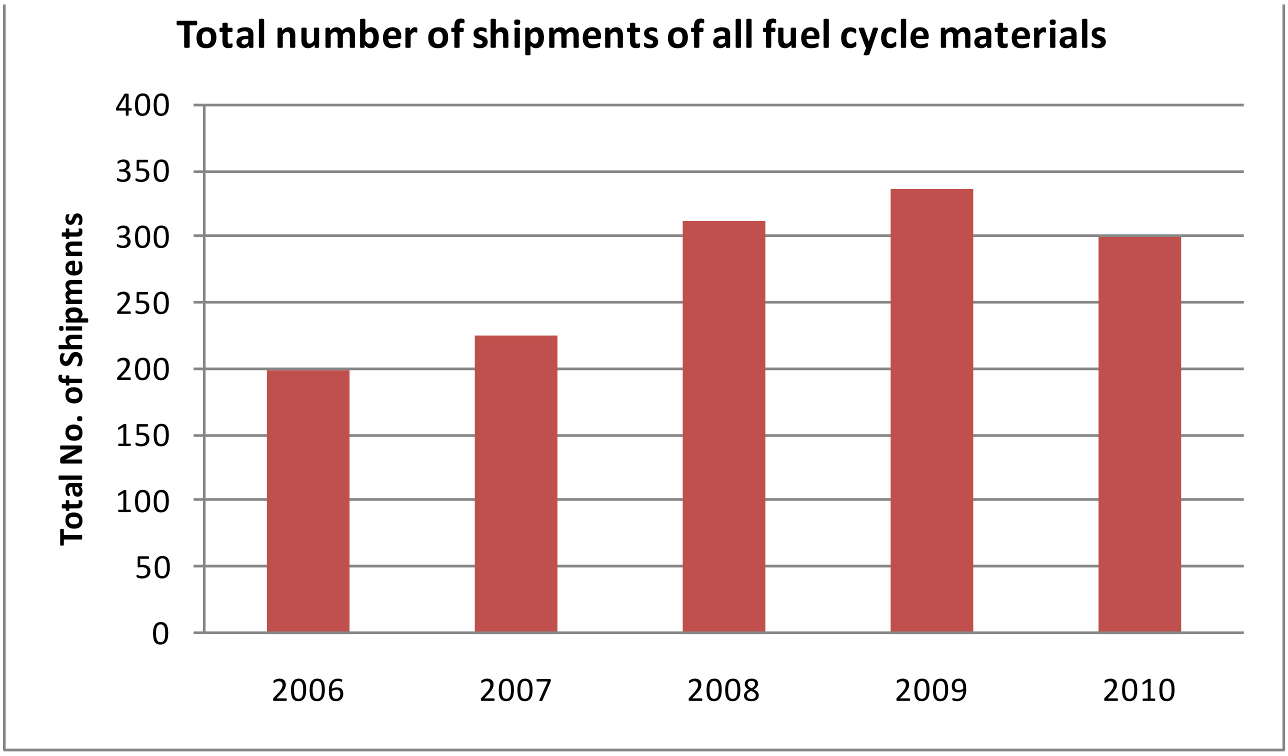

**Figure 7 - numbers are excluding shipments from Transport Stage 1 - as only 2 years data for this transport stage*

Changes can occur however, whenever there are contract changes between companies in the nuclear fuel cycle. As with any industry there will be competition for contracts. Factors such as new enrichments facilities in the USA, the possibility of international waste repositories and more decommissioning of old reactors may also influence the frequency and routes of fuel cycle transports.

A current route for the transport of vitrified HLW is from Workington to Japan. There are around 750 more canisters of HLW to be returned to Japan from Sellafield that are planned to be shipped there over the next ten years. Another planned future shipment is of Canadian steam generators from Canada to Sweden for recycling.

To date there has never been a transport accident involving a release of radioactive materials. However there have been several incidents involving ships used to transport nuclear fuel cycle materials including ones when these materials were being carried: including the MV Puma taking on water on the return journey from delivering irradiated fuel to Murmansk in 2010, the Kapitan Lus colliding with a methanol tanker between Denmark and Sweden while she was carrying uranium oxide and the Mont- Louis sinking in 1984 with a cargo of uranium hexafluoride (UF_6).

KIMO is a concerned that transport of nuclear fuel cycle materials are undertaken using the highest safety standards, as a transport accident involving a release of radioactive materials would have harmful effects both on the health and the reputation of coastal communities causing physical, economical and environment damage to people and the natural heritage of the area. As this report shows there are many shipments through Northern European Waters, on regular freight services for unirradiated fuel materials and on specially certified vessels for HLW, irradiated fuel and plutonium.

KIMO would like to see an end to all shipments of nuclear waste (irradiated fuel, HLW and other back end materials from and for reprocessing) and MOX fuel, as stated in KIMO Resolutions 1/96, 5/01 and 6/01. However if they do occur then they should be undertaken only using the highest available safety standards of ship, packaging and security arrangements.

9. Appendices

Appendix 1: Nuclear Fuel Cycle Steps and Transport Stages in the Fuel Cycle

	Nuclear Fuel Cycle	
Step 1	Mining and Milling	*Front End*
Step 2	Uranium Conversion	
Step 3	Uranium Enrichment	
Step 4	Fuel Fabrication	
Step 5	Electricity Generation	
Step 6	Storage of Spent Fuel and Wastes	*Back End*
Step 7	Reprocessing of Spent Fuel	
Step 8	Disposal of Waste Products	
	Decommissioning of Nuclear Reactors	
	Transport Stages in Fuel Cycle	
Transport Stage 1	Mining to Conversion	*Front End*
Transport Stage 2	Conversion to Enrichment	
Transport Stage 3	Enrichment to Fuel Fabrication	
Transport Stage 4	Fuel Fabrication to Electricity Generation	
Transport Stage 5	Back End Materials	*Back End*
	Decommissioning	

Appendix 2a: European countries operating nuclear power

European Countries Operating Commercial Nuclear Reactors in 2010	
Armenia	Romania
Belgium	Russia
Bulgaria	Slovakia
Czech Republic	Slovenia
Finland	Spain
France	Sweden
Germany	Switzerland
Hungary	Ukraine
Netherlands	United Kingdom

Source: WNA, World Nuclear Power Reactors.

http://www.world-nuclear.org/info/reactors.html

Appendix 2b: Numbers of reactors in EU countries

Number of operating reactors in current EU Countries

(above countries excluding Armenia, Russia, Switzerland and Ukraine)

Year	Number	Year	Number
2000	147	2006	144
2001	144	2007	145
2002	144	2008	145
2003	144	2009	144
2004	144	2010	143
2005	144	2011	143

Source: WNA, World Nuclear Power Reactors. Euratom Annual Reports 08-10

Appendix 3: Data Sources

Sources of Data

Authorities Providing a full disclosure

UK Office of Civil Nuclear Security
-movements of civil nuclear material on UK flagged vessels (2006-present)
-RoRo movements of civil nuclear material through Uk ports (2006 present)
-Movements of civil nuclear material through Uk ports (2006 present)

The Federal Office for Radiation Protection – Germany
-table of currently approved transports – fissile substances and non fissile substances with activity greater than 1000 TBq

Parliament of the Free and Hanseatic City of Hamburg
Transports of Radioactive Material through the Port of Hamburg 2006-2010

STUK – Radiation and Nuclear Safety Authority – Finland
Nuclear fuel transports through Finnish ports

Authorities providing Limited Information

FANC – Federal Agency for Nuclear Control – Belgium
Numbers of transports through Belgian Ports – no destination/ receiver

Ministry of Economic Affairs, Agriculture and Innovation – Netherlands
Transport Permits 2007 – 2010

Countries in area of study unable to disclose transport Information

Spain
Sweden
Norway (through territorial waters)
France (unable to obtain definitive answer, unlikely to disclose data)

Press Releases

The following sources also contributed to back end transport data:
Barents Observer
en.rian.ru
Bellona
Cumbrians Opposed to a Radioactive Environment (CORE)
World Nuclear News
Greenpeace

Appendix 4: Methodology for Data Processing and Recording

Data from the sources listed in Appendix 3, was combined to form the average transport numbers over each of the routes shown in the maps, for each of the nuclear fuel cycle transport stages.

The main source of data for this report was Government records, as the transport of radioactive materials through a port is recorded by that country or if shipments are not individually recorded a licence for transport was – for many of the countries in Europe whom were contacted. Data from the UK Office for Civil Nuclear Security was obtained through a Freedom of Information Request and similarly data from other countries were then obtained.

The shipments recorded do not only pass through one particular port of interest and there have been occasions where a shipment has been recorded in both German and UK data. In this case to balance the additions sheet, in the latest additional data, shipments previously recorded were omitted.

This way ensured that no shipments are recorded twice.

What is actually recorded in our spreadsheets is the numbers of packages being transported by sea and not the number of discrete shipments or vessels each carrying a cargo of nuclear materials. However many of the listed packages are transported on separate vessels, indicated by the destinations and notification or transport dates. In other cases two or three of the packages could be transported aboard the same vessel. Sometimes this is obvious and for others it is not possible to say whether packages are aboard separate ships.

The numbers of shipments listed is then less than the number of individual vessel movements of nuclear cargo but it gives a good indication. It is not possible to count the number of discrete vessel movements so the number of packages being transported is the figure being counted and referred to throughout this report as shipments.

The transports initially were recorded as moving between particular fuel cycle facilities in two countries. In the additions spreadsheet, sea shipments of particular materials were recorded going between countries, regardless of the particular fuel cycle facility. These were then averaged over 5 years (2006-2010) as this was when the majority of the data recorded is from. The exception was step 1 (transports of U_3O_8), only data from Hamburg has records of this in 2009-2010; these were averaged over 2 years.

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Photo Acknowledgements

Front Cover - Crane lowering MOX containers into hold of nuclear waste carrying ship Pacific Swan.
19/12/2000 © Greenpeace / Pierre Gleizes
Locations: Cherbourg, France

Picture 2 + 8 - Cattenom Nuclear Power Plant, France. Author: Stefan Kühn. Source Wikimedia Commons

Picture 3 - Crane lowering MOX containers into hold of nuclear waste carrying ship Pacific Swan.
19/12/2000 © Greenpeace / Pierre Gleizes
Location: Cherbourg, France

Picture 4 - Ranger Uranium Mine, Northern Territory, Australia. Author: Geomartin. Source Wikimedia Commons

Picture 5 - 7 - Work of US Federal Government

Picture 9 - Work of US Federal Government. Source Wikimedia Commons

Picture 10 - MOX container being unloaded from train onto quayside to be loaded onto ship Pacific Swan. Workers on rightside, next to train. Container in the air on crane. 19/12/2000
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Location: Cherbourg, France

Picture 11 - Pacific Egret - image courtesy of the Nuclear Decommissioning Authority

Picture 12 - Atlantic Osprey - image courtesy of International Nuclear Services

Picture 13 - MOX transport ship Pacific Swan berthed in Cherbourg harbour, being loaded with MOX fuel. France Ship seen in distance on quayside, crane holding container over ship. 19/12/2000
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