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For the record we would like to stress that the firms, industries and public agencies mentioned above are not responsible for the contents of this report.

Preface

Bellona visited the Sellafield reprocessing plant for the first time in 1995. Since then, we have worked purposefully towards obtaining an overview of the environmental risks that certain parts of the facility represent, as well as to gain an understanding of the clean-up tasks Britain is facing. The information in this report is therefore based both on formal studies and material that we have collected over the course of several visits to the site.

Bellona Report No. 8: Sellafield gives an overview of the information that Bellona has thus far assembled about the British reprocessing facility Sellafield. As a rule, it is discharges of radioactive substances from the facility that capture the attention of the media; however, there are also a number of other important challenges facing Sellafield. From the time that the facility was completed in the early 1950s, Sellafield has been closely associated with the British nuclear weapons program. Hence it is not only discharges of radiation from the facility that cause concern. Fifty years of British weapons development and nuclear research have also left in their wake a number of problems bearing on the handling of nuclear waste. One of the largest challenges is how to handle the 1570 m^3 of highly active liquid nuclear waste that is presently being stored in tanks inside the facility. Just for caesium-137 alone the current amount of activity in these tanks is equivalent to 100 times the amount of radioactivity that was released as a result of the Chernobyl accident. The tank facility at Sellafield therefore constitutes a major risk factor, not only for the immediate environs, but also for neighbouring countries. Likewise Sellafield's storage of 80 tonnes of plutonium constitutes a serious hazard to the natural environment. This waste must be handled in a responsible manner and placed in a repository.

For many years Bellona's work has focused on the major clean-up efforts in Northwest Russia left in the wake of the cold war. Nevertheless it is not these sources that account for the radioactive pollution measured in the Barents Sea. Measurements of radioactive waste in the Barents Sea indicate that the historical releases of radioactivity from Sellafield, along with fallout from nuclear test explosions at Novaya Zemlya are the primary culprits. Today it is the large releases of the radioactive element technetium-99 (Tc-99) from Sellafield that is largely responsible for the pollution of the Norwegian coast and the Barents Sea.

At the same time this very concrete case shows that Bellona's political efforts are effective. In the spring of 2003, Bellona and the political action group "Lofoten against Sellafield" initiated a conference in Sellafield with a focus on Tc-99. Here, in Cupertino with British Nuclear Fuels Plc (BNFL), evidence was presented to show that these discharges of radioactivity could effectively be halted in the expectation of the development of new purification technology for Tc-99. The response came very quickly. The British Government has now requested BNFL to halt releases of Tc-99 in expectation of the new purification technology. Experiments in purification by chemical means through the use of the precipitant TPP began in October 2003. A final decision regarding the Tc-99 discharges is expected to be announced in March 2004. The Sellafield matter is under continual development, and you may find the latest updates on our web site, www.bellona.org.

We would particularly like to thank certain institutions and individuals who have assisted us in our efforts to gather and analyse the information in this report. Martin Forwood from "Cumbrians Opposed to a Radioactive Environment (CORE) was helpful in providing information and guiding services in the local community around the Sellafield plant. BNFL has made available information and illustrative material, showing Bellona around the facility on several occasions. The Norwegian Radiation Protection Authority has analysed the samples that Bellona has taken of lobsters off the Norwegian coast. Bellona also owes great thanks to supporters who have made financial contributions to the preparation and production of this report.

I would personally like to thank my colleagues at the Bellona Foundation, Frederic Hauge and Nils Bøhmer, for assisting both in the obtaining of factual information and for professional discussions. Thanks too to Marius Holm who provided information concerning the effects of radiation releases on Norwegian aquaculture and ocean farming.

Last but not least, I would like to thank the initiators of "Lofoten against Sellafield" for an inspiring and productive co-operation.

Oslo, 20 December 2003
Erik Martiniussen

Abbreviations

Alpha particles: Radiation consisting of two protons and two neutrons.
Am-241: Americium-241.
B204: The first reprocessing Plant at Sellafield.
B205: Magnox Reprocessing Plant.
B215: Storage building at Sellafield for highly active liquid waste.
B211: Tank facility at Sellafield containing large amounts of Tc-99 waste.
Beta particles: Radiation consisting of one electron.
BNFL: British Nuclear Fuel Plc; British nuclear power company.
Becquerel (Bq): Unit for measuring radioactivity; 1 Bq = 1 disintegration per second.
Co.60: Cobalt-60.
Cs-137: Caesium-137.
DEFRA: Department for Environment, Food and Rural Affairs.
EA: Environment Agency; British environmental directorate.
EARP: Enhanced Actinide Removal Plant; purification plant at Sellafield.
FSA: Food Standard Agency.
Gamma radiation: High energy electromagnetic radiation.
GBq: Gigabecquerel (1 GBq = 1000 MBq).
H-3: Tritium.
ICRP: International Commission on Radiological Protection.
HAL Highly Active Liquor: high level waste in liquid form.
HSE: Health and Safety Executive; British safety inspectorate.
MAC: Medium Active Concentrate; medium active liquid radioactive waste.
MBq: Megabecquerel (1 MBq = 1 million Bq).
MDF: MOX Demonstration Facility.
MOX: Mixed Oxide Fuel; nuclear fuel produced from uranium and plutonium.
NII: Nuclear Installation Inspectorate.
NIREX: Nuclear Industry Radioactive Waste Management Executive.
OSPAR: Oslo-Paris convention for the protection of the marine environment in the North-East Atlantic.
Pu: Plutonium.
PBq: Petabecquerel = 1015 Bq.
RPII: Radiological Protection Institute of Ireland.
Ru-106: Ruthenium-106.
SEPA: Scottish Environment Protection Agency.
SIXEP: Salt Evaporator and Site Ion Exchange Effluent Plant; purification facility at Sellafield.
SMP: Sellafield MOX plant.
Sr-90: Strontium-90.
TBq: Terabecquerel = 1012 Bq. (1 TBq = 1000 GBq.)
Tc-99: Technetium-99.
THORP: Thermal Oxide Reprocessing Plant.
TPP: Tetraphenylphosphonium bromide. A chemical that potentially could be used in EARP to precipitate Tc-99 in a solid form.
UKAEA: UK Atomic Energy Agency.
WVP: Waste vitrification plant.

Contents

Introduction

The English reprocessing plant Sellafield is located on the northwest coast of England, 20 kilometres north of the seaport town Barrow-in-Furness on the Irish Sea. The plant is operated and owned by British Nuclear Fuels Plc. (BNFL), which is a one hundred percent government-owned company. The plant is one of the three remaining reprocessing plants in the world. In addition to Sellafield, there are civilian commercial reprocessing plants in France (La Hague) and in Russia (Mayak). The second British reprocessing plant at Dounreay (on the northern point of Scotland) was shut down in 1996.

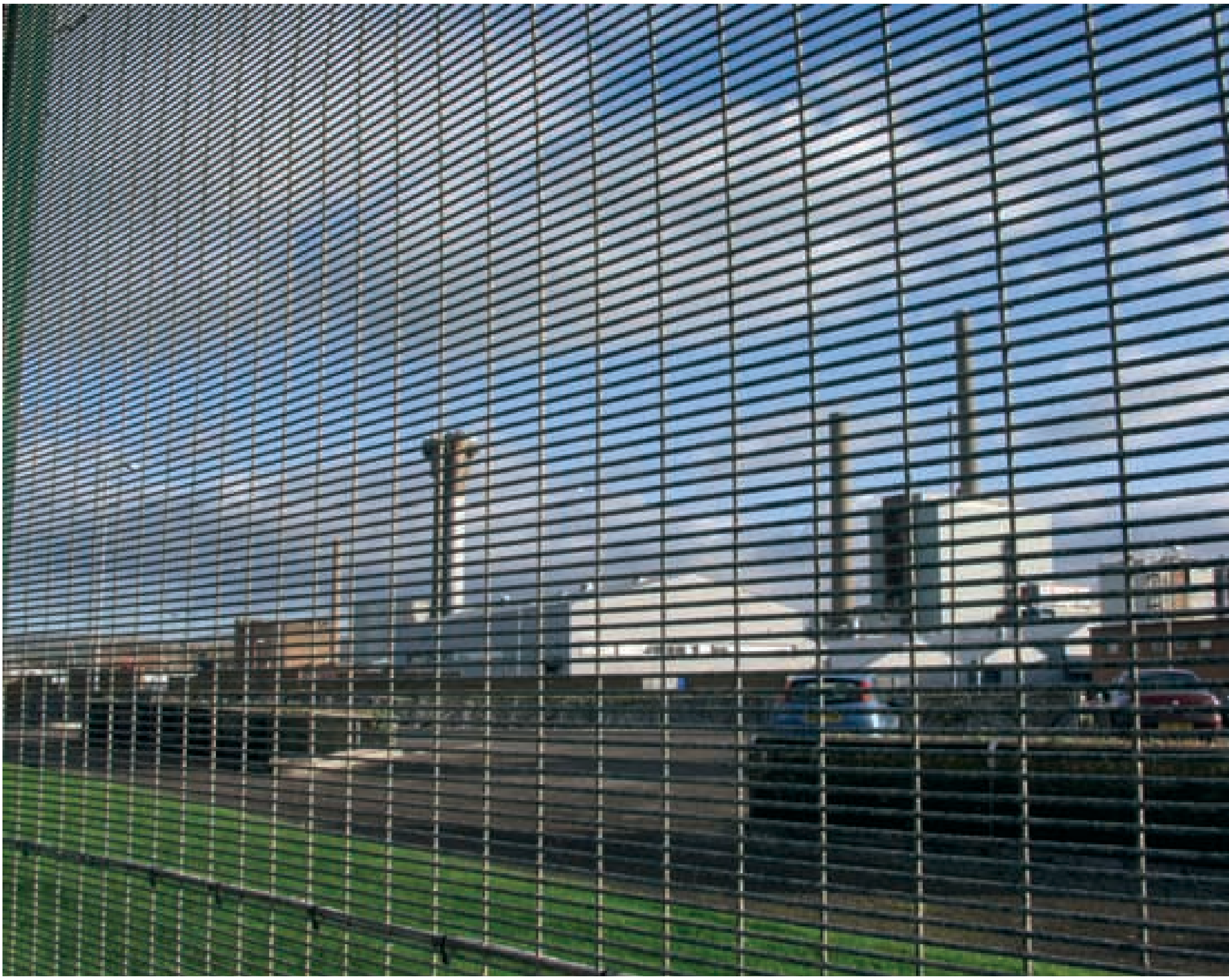
Today there are two reprocessing plants operating at Sellafield and one plant for the treatment of high-level liquid waste. In addition, there are several reactors and plants that are shut down and in the process of being decommissioned. It is the two reprocessing plants that cause the largest radioactive discharges from Sellafield, the contents of which can be traced from the Irish Sea north to the coast of Norway and up to the Barents Sea, reaching as far north as Spitsbergen.

The largest concentrations of radioactivity may be found along the coastline off the Sellafield site itself. In this area, higher concentrations of plutonium have been detected than those that can be meassured in the area around Chernobyl. Radioactive contamination has been traced in shellfish, fish, and seaweed, to ocean water, sediments on the bottom of the Irish Sea and in sand on the beaches. In the years to come, BNFL plans to increase activity at its two reprocessing plants at Sellafield, and this will naturally lead to further increases in radioactive discharges.

Reprocessing is a method of handling spent reactor fuel. A number of nuclear powers, such as the United States and Sweden, have opted to store their spent reactor fuel, while others, including the United Kingdom and France, have opted to reprocess the fuel. In essence, reprocessing entails dissolving the spent fuel in acid so that the uranium and plutonium can be isolated from the waste and reused as fuel for nuclear reactors. However, when the fuel is dissolved in acid, all the other radionuclides that were formed while the fuel was in use in the reactor, are released. These take the form of waste products as strontium-90, caesium-137 and technetium-99, all of which are elements of no practicable use. Most of the radioactive substances can now be cleansed out of the liquid waste and stored on shore, but the remaining waste is still discharged directly into the sea in low or medium active concentrations.

During the 1950s and 60s, Sellafield had a central role in the British nuclear weapons programme. At that time, reprocessing was carried out in order to separate plutonium-239, which was then utilised in the British nuclear weapons arsenal. Reprocessing was later continued in order to reuse the plutonium and uranium in fast breeder reactors. In principle, these reactors are powered by plutonium fuel while simultaneously generating more plutonium, which can then in turn be reused as fuel for the reactor. However, the development of fast breeder reactors did not go as expected, with the result that Great Britain terminated its research programme on this technology in 1994.

With the fast breeder programme having been terminated, there are few compelling reasons today to continue reprocessing spent nuclear fuel. Hence BNFL now endeavours to promote reprocessing as a means of recycling uranium and plutonium for reuse in so-called Mixed Oxide Fuel (MOX). However, most of the plutonium that is stored at Sellafield belongs to BNFL. Since British nuclear reactors are not powered by MOX fuel, there are no concrete plans for what to do with this plutonium which now amounts to 55 tonnes. There is a



The Sellafield reprocessing plant on the North West Coast of England.

further 25 tonnes of plutonium owned by other customers which has not yet been utilised in MOX fuel. At the same time, BNFL is experiencing a flight of customers. Certain key customers have said that they are beginning to lose all faith in the company, and in 2002, BNFL posted a loss of £1 billion. The British government has long had plans to privatise BNFL, but after last year's disastrous losses; these plans have now been put on ice.

This report describes the historical activity at Sellafield, from the beginning of production of weapons-grade plutonium in the 1950s to today's commercial reprocessing at THORP. It describes the radioactive discharges and contamination caused by these activities. Along the Norwegian coastline today, increased levels of the radioactive substance technetium-99 (Tc-99) are being measured, an element which has a half-life of 213,000 years. The concentrations of Tc-99, particularly noticeable in lobster and seaweed, have made a marked increase over the last few years.

The Bellona Foundation calls for an immediate halt of the radioactive discharges from Sellafield. Bellona sees no rational reason to produce further amounts of the extremely radiotoxic substance plutonium. As Russia and the United States comply with the terms of the disarmament agreement START 2, the world stockpile of stored plutonium will become very large. Furthermore, continued production of plutonium is inconsistent with efforts to halt the proliferation of nuclear weapons. For these reasons, Bellona calls for an end to reprocessing activities.

Chapter 1
Nuclear reactors at Sellafield

Nuclear reactors at Sellafield

As of 2003, the United Kingdom has 27 operative nuclear reactors dispersed between 12 nuclear power plants. Of the British reactors, 12 are of the older, gas-cooled and graphite moderated Magnox type, while 14 are Advanced Gas-cooled Reactors (AGR). The most recent reactor to be put into operation in Great Britain was the pressurised water reactor Sizewell B, which went into operation in 1995. Today, the United Kingdom is the only country in the world that still operates gas-cooled reactors. Both Magnox reactors and AGRs use carbon dioxide as a coolant.

At Sellafield itself, there are no longer any reactors in operation. The last British nuclear power plant to be shut down was the Calder Hall power plant with its four gas-cooled and graphite moderated reactors. Within the Sellafield site, there are seven shut down reactors, and the work to decommission them is both expensive and difficult. In this chapter, we examine the different reactors at Sellafield that are to be decommissioned.

1.1 Historical background

Great Britain was active in the development of nuclear weapons during World War 2 and was a participant in the American Manhattan Project, which developed the world's first nuclear bomb. In the aftermath of the war, the British government decided to launch a British nuclear weapons program, and it was to this end that the Windscale facility (to be later renamed Sellafield) was ordered to be built in 1947. The first two reactors at the Sellafield plant were the so-called Windscale Piles. These were a very particular type of air-cooled and graphite-moderated reactor and were used exclusively to produce plutonium for the weapons industry. The plutonium generated here was then transported to Aldermaston where nuclear bombs were manufactured. In 1952, Britain exploded its first nuclear device over Montebello Island in Australia.

For a long period there was virtually no distinction between the British civilian nuclear programme and the country's military nuclear programme. The earliest Magnox reactors produced weapons grade plutonium, while simultaneously generating electric power. It was not before the establishment of BNFL in 1972 that there was any real delineation between the civilian and military nuclear industry. Military nuclear fuel can still be handled separately at the Sellafield facility; on these occasions, IAEA monitoring routines are suspended. [1]

1.2 Windscale Piles

The first two reactors to be put into operation at Sellafield were the so-called Windscale Piles. These reactors were part of a top secret weapons programme which also involved the building of the first reprocessing plant (B204) and a common storage pool (B29) to receive the spent nuclear fuel from the two reactors. Each of the reactors contained 1 966 tonnes of graphite and were 7.43 metres high and 15.32 metres in diameter. They had 3 444 fuel canals, 977 horizontal isotope canals, and a thermal effect of 180 MW. The reactors utilised fuel rods of metallic uranium 285 mm in length and 25 mm in diameter. The fuel had an average burn-up of 300 MWd/t.[2] so as to most effectively increase production of weapons-grade plutonium (Pu-239).

Spent nuclear fuel from the Windscale reactors was handled in B204 for the entire period that they were in operation. The two reactors produced 35 kg of weapons-grade plutonium every year; in the period between 1951-1957, the B204 reprocessing plant produced a total of 385 kg of weapons-grade plutonium from their fuel.[3] It was reprocessed plutonium from the Windscale Piles, which went to make the United Kingdom's first nuclear bomb. This was exploded over the Montebello Islands in Australia in October 1952, making Great Britain the world's third largest nuclear power after The United States and the Soviet Union.[4]

The two Windscale Pile reactors were operative from 1950 to 1957, when a serious fire in reactor no.1 caused radioactive contamination over a large area. The accident showed that there were very serious flaws in the design of air-cooled reactors, both from a technical and safety point of view. The combination of flammable graphite in the reactor core and the supply of air as coolant, was a

Reactor	Reactor type	Power	Start of operations	Shut down
Windscale Pile 1	ACR	180 MWt	1951	10/ 1957
Windscale Pile 2	ACR	180 MWt	1951	10/ 1957
Calder Hall 1	GCR (Magnox)	50 MWe	05/1956	31.03/ 2003
Calder Hall 2	GCR (Magnox)	50 MWe	11/1956	07/ 2001
Calder Hall 3	GCR (Magnox)	50MWe	03/1958	07/ 2001
Calder Hall 4	GCR (Magnox)	50MWe	12/1958	07/ 2001
Windscale AGR	AGR	36 MWe	08/1962	04/ 1981

Table 1: Reactors at the Sellafield site. MWe = electrical power, MWt = Megawatt thermal effect

1 Eriksen, V.O. 1995, page 45.
2 The first phase of decommissioning of the Windscale Piles, www.ukaea.org, 06.07.01
3 Albright, Berkhout and Walker, 1993: page 59
4 Bunyard, P. 1986. The Sellafield Discharges.

ticking firebomb. After the fire, it was decided to shut down the remaining reactor for safety reasons, and no further air-cooled reactors of this type were ever built. The fire in reactor no.1 is further discussed in chapter 4.2.

In the period 1958-1961, the immediate vicinity around the reactors was cleansed of radioactive fallout so that the rest of the plant could resume normal operation. The remaining undamaged fuel inside reactor no.1 was removed, and reactor no. 2 was likewise emptied of fuel. Control rods were pushed deep down into the damaged reactor core, and the entire reactor was then encased in cement. The reactors remained this way until 1990 when the British government effected a programme to decommission them. There are allegedly about 17 tonnes of melted and partially damaged reactor fuel still remaining within reactor 1.[5] Other sources however assert that there are 15 tonnes.[6] The UK Atomic Energy Authority (UKAEA) estimates today that there are more than 6 700 damaged fuel assemblies inside the fire-ravaged reactor, and there is some doubt therefore as to whether it will be possible to dismantle the reactor at all.[7]

Today it is UKAEA who is responsible for the Windscale reactors, but as the leader of a consortium consisting of BNFL, Rolls Royce and NUKEM, BNFL has been received the contract to decommission the fire-damaged reactor. Efforts to decontaminate the tall chimneystacks that is the hallmark of the two reactors are already underway. While the stack on reactor 2 has now been torn down, work on reactor 1 has barely begun. Intense radiation from the reactor core prevents human access to the airshafts. Consequently, BNFL is utilising robots for this difficult task.

Work is also underway to cleanse the water ducts that lead out from the two reactors. There used to be a common storage pond (B29) between the two reactors to temporarily store spent fuel. The fuel would be transferred from the reactors to the pond by means of a special system of water ducts. This system was badly contaminated by radiation after the 1957 accident. In 1999, after ten years of work, the radioactive sludge from the contaminated canals was finally drained and cleaned out before being transferred to the old fuel storage pond (B29). A further 210 old fuel rods were also found on the bottom of the empty canals.

It is unknown how long it will take to decommission the two reactors. So far, only the stack of reactor number 2 has been dismantled, and studies are being made as to how to dismantle the undamaged reactor. The safe dismantling of the fire-damaged reactor will obviously be an even bigger challenge.

1.3 Calder Hall

Prime Minister Winston Churchill ordered the building

Windscale Piles. Shut down after a catastrophic fire in reactor no. 1 in 1957.

5 The Daily Telegraph, January Friday 1,st 1988.
6 Nuclear Engineering, April 2003, page 10: "Software helps remove Pile 1 at Windscale".
7 The first phase of decommissioning of the Windscale piles, www.ukaea.org, 06.07.01

There are four Magnox reactors at the Calder Hall nuclear power plant. This photograph was taken in 1998 when all four reactors still were in operation.

of four reactors at Calder Hall in 1953. The original plan was to build only one reactor, but it was later decided to build two power plants, each with two reactors - Calder Hall A and B. Three years later, on October 17, 1956, the first reactor was officially opened by Queen Elizabeth II.[8]
The four reactors were officially shut down in March 2003, at which time the oldest reactor had been in operation for almost 57 years.
All four of the Calder Hall reactors were Magnox type reactors, gas-cooled by carbon dioxide and graphite moderated. The reactor core consisted of a several graphite chips, each with a cooling canal in the middle. Work to empty the reactors of spent nuclear fuel was begun in 2003. The name Magnox comes from the special fuel that is utilised in the reactors. While most nuclear reactors today utilise fuel in the form of uranium oxide (UO_2), the Magnox reactors utilise natural metallic uranium which is encased into a special cladding of magnesium oxide - hence the name Magnox (more about Magnox reactors in Appendix 3.)
The fuel rods at Calder Hall were approximately one metre long and five centimetres in diameter, and weighed between 10 and 12 kilos.[9] The gas was lead from the bottom of the reactor tank, up through the reactor core, and out to the top of the reactor tank. This heated up the water in the secondary circuit and turned it to steam, and this in turn powered an electricity generator. The pressure in the secondary circuit (which consisted of water) was higher than the pressure in the primary circuit, which consisted of gas. The steam was then cooled to form water inside large turrets. Most Magnox reactors have large, round reactor tanks to relieve the pressure inside the reactor. However, the four Calder Hall reactors utilised a cylindrically shaped Magnox reactor

8 BNFL press release, 02.09.1996.

9 Wise News Communiqué (no. 552). 2001

Windscale AGR, better known as the Sellafield Golf Ball.
The reactor was closed in April 1981.

tank, something that had the effect of increasing the load on the reactor tank. The reactor tank itself was built into a giant square-shaped concrete colossus to protect against radiation. One of the weaknesses of the British Magnox reactors is that they, like many of the Russian plants, lack secondary reactor containment.[10] It was the presence of just such containment that to a large extent reduced the emission of radioactivity during the 1979 accident at Three Mile Island in the United States. The reactors at Calder Hall played a central role in the United Kingdom's nuclear weapons programme. In the 1950s there was a rising demand for weapons-grade plutonium, and hence it was planned that the reactors at Calder Hall along with four new reactors at Chapelcross in Scotland would supply the necessary quantity of weapons-grade plutonium. It is thought that Calder Hall was also supplying the British military with weapons-grade plutonium late into the 1970s. Two of the Calder Hall reactors are thought to have been utilised to produce weapons-grade plutonium in 1978 and 1979; it is also believed that the reactors were producing 400 kilograms of weapons-grade plutonium as recently as 1986-1989, which was reprocessed in B205 and delivered to the British Army.[11] Thus it is thought that the four reactors produced in sum over two tonnes of weapons-grade plutonium.

However, despite their military associations, the Calder Hall reactors were also a link in the "civilising" of nuclear power in that they were also the world's first nuclear reactors to be employed in the production and supply of electricity. Originally, the power plant was built, owned and run by UKAEA. Today BNFL owns the plant, which is now ready to be decommissioned.

Production capacity was comparatively low in all of the reactors, with a power output of only 50 MWe compared

10 Naderson, R. *et al.* 1986, Summary and conclusions.

11 Albright, D. *et al.* 1997, page 62.

to most modern nuclear reactors today which produce over 1 300 MWe. At the same time, the power output of the four reactors was only 19% of their total efficiency, whereas the more modern AGR reactors have an efficiency of approximately 40 percent.[12]

1.4
Windscale AGR

Windscale/Sellafield was the first nuclear facility in the world to construct an advanced gas-cooled reactor (AGR). Construction of Windscale AGR began in 1958, and the reactor was started up for the first time in 1962. The new reactor was a test model for the new generation of AGR reactors, and had a capacity of about 30 MWe.

Windscale AGR was a further development of the Magnox reactors. However, the fuel cladding in this reactor was constructed of stainless steel as opposed to Magnox, and its fuel was not metallic, but ceramic uranium oxide enriched to just above two percent.[13]

A further developed model of the AGR went on to become the most common reactor of the 1970s and 1980s. In contrast to the Magnox reactor, this new generation of AGR-type reactors had a much higher power production capacity; up to 600 MW. However, in common with the Magnox reactors, all AGR reactors are graphite-moderated and cooled with carbon dioxide.

In addition to the prototype test reactor at Sellafield, a further 14 AGR-type reactors were built, most of them in the late 1970s and early 1980s. The last AGR-type reactor was completed in 1989. Although the Windscale AGR was shut down in April 1981, the remaining 14 reactors remain in operation and produce 16 percent of the United Kingdom's total electricity supply.

Today, the Windscale AGR is the centrepiece of the UK Atomic Energy Authority's (UKAEA) decommissioning programme for nuclear reactors. The estimated costs for decommissioning the reactor currently lie at about 80 million pounds.[14] The last parts of the reactor's graphite core were removed in April 2003.[15] The process of de-commissioning the entire reactor will not be completed until the year 2130, following a 100-year monitoring period.[16]

12 Nuclear Engineering International, 2001;
World Nuclear Industry Handbook 2001: page 164.
13 Ibid
14 UKAEA, 2001: Remote Control (Phase 1 Decommissioning, Windscale Pile 1)
15 Nuclear Engineering, April 2003, page 2.
16 UKAEA, 2001: Remote Control (Phase 1 Decommissioning Windscale Pile 1).

Chapter 2
Reprocessing facilities

Reprocessing facilities

Three reprocessing facilities have been in operation at Sellafield, with the first plant (B204) commencing operations as early as 1951. This plant was utilised solely to produce plutonium for Great Britain's weapons programme. In 1964, the B204 plant was shut down, and since then, a further two plants have been built: the Magnox Reprocessing Plant (B205), which began operations in 1964, and the Thermal Oxide Reprocessing Plant (THORP), which was finally ready to commence operation in 1994.

2.1 The reprocessing plant B204

B204 was Great Britain's first reprocessing plant, taking the form of a military facility with a capacity of 300 tonnes of fuel annually, or a maximum of 750 tonnes of low burn-up fuel.[17]

In April 1952, the first production of plutonium was delivered from Windscale to Britain's nuclear weapons laboratory at Aldermaston. Six months later, in October 1952, the United Kingdom detonated its first nuclear device over Montebello, Australia, thereby becoming the world's third nuclear power.[18]

B204 produced a total of 3.6 tonnes of weapons-grade plutonium, of which nearly 400 kilograms were manufactured in the period 1951-1957 out of fuel originating from the Windscale reactors. A further three tonnes were produced from fuel from Calder Hall and Chapelcross, while another 400 kilograms were produced from fuel coming from other Magnox plants. Much of the weapons grade plutonium that UKAEA produced for the British armed forces was produced in "civilian" (non-military) Magnox reactors, and it was not until 1969 that a clear distinction was made between civilian and military plutonium. Prior to 1969, distinction was only made between weapons-grade plutonium with its high concentration of Pu-239, and reactor plutonium.[19]

In 1964, B204 was replaced by a larger reprocessing plant (B205), which would also be utilised for the reprocessing of fuel for civilian uses. With a production capacity five times greater than that of B204, the new plant (B205) could reprocess fuel from Magnox reactors throughout the United Kingdom. The military reprocessing plant B204 was consequently converted into a pre-treatment plant where uranium oxide spent nuclear fuel from the new generation of AGRs could be pre-treated prior to reprocessing in B205. The B204 plant also accepted fuel for pre-treatment from foreign boiling water reactors and pressurised water reactors prior to further reprocessing of the fuel in B205.

The conversion of B204 to a pre-treatment facility was completed in 1969.

In 1972, B205 was shut down for one year for repairs, and as a consequence B204 also had to be closed. The pre-handling plant was supposed to reopen on September 26, 1973. However, when the operators started up the plant, a chemical reaction occurred which released a cloud of radioactive gas. The entire plant was contaminated by radiation, and 34 workers were exposed to radioactive ruthenium-106. After that, B204 was never taken into use again.[20]

The B204 reprocessing plant.

2.2 Magnox Reprocessing Plant (B205)

Sellafield Magnox Reprocessing Plant (B205) was completed and began commercial operation in January 1964. The plant is still in operation and has a capacity of 1 500 tHM/y. However, in the last five years B205 has reprocessed less than 800 tonnes of fuel per annum. The plant utilises the Purex method (Plutonium Uranium Extraction), which is the most common method of

17 D. Summer, R. Johnson, W. Peden, in Makhijani A. *et al.*, 2000., page 412.

18 Bunyard, P. 1986: The Sellafield Discharges.
19 Albright, D. 1997, pp. 59 - 66.
20 May, J. 1989, page 188.

reprocessing spent nuclear fuel today.[21] The process utilises the extraction agent tributyl phosphate (TBP).
Following the closure of the pre-treatment plant (B204) in 1973, the B205 Magnox plant has only processed metallic uranium fuel. Today the facility reprocesses fuel solely from British Magnox reactors. The reprocessing plant consists of several buildings and both the extraction agent and solutions of uranium and plutonium are transported from building to building by means of pipelines. Any leakage from one of these pipelines would result in a direct discharge of radioactivity into the air.
The plant was originally built and run by UKAEA, but in 1971 the wholly government-owned company British Nuclear Fuel Plc (BNFL) was founded to run the plant. The opening of the B205 reprocessing plant has had the effect of causing Sellafield to be considered a civilian nuclear plant to a greater and greater degree. Other factors contributing to this "civilisation" of Sellafield was BNFL's efforts in the 1970s and 1980s to promote the idea of reprocessing as an effective means of handling spent nuclear reactor fuel from civilian nuclear power plants. Furthermore, the company was entering into contracts to reprocess foreign nuclear fuel.
For the first 30 years, over 35 000 tonnes of Magnox fuel and more than 15 000 tonnes of uranium were reprocessed at the B205 plant. Most of the plutonium that was and continues to be produced is being stored at the plant. In May 2000, BNFL announced its intention to phase out the great majority of the Magnox-reactors by the end of 2010. The company intends to cease production of Magnox fuel at Springfields in the same year. Consequently, BNFL plans to close the B205 Magnox reprocessing plant around 2012 when all the Magnox fuel will have been reprocessed. If these plans are to come to fruition, BNFL estimates that the B205 plant will have to reprocess 1 000 tonnes of spent Magnox fuel a year until 2012. [22]
In the two years since this decision was made, B205 has handled about 1600 tonnes of fuel, although the actual goal for this period was 2000 tonnes. Closure of the B205 plant by the close of 2012 will therefore require that the facility operates without any problems in the coming years.

2.3 Thermal Oxide Reprocessing Plant (THORP)

Following the closure of B204 in 1973, it was no longer possible for the British to reprocess the increasingly common uranium oxide fuel. This badly disrupted BNFL's commercial plans to reprocess fuel on commission from foreign countries. Consequently, plans were made to build an additional reprocessing plant that could accommodate this type of fuel.

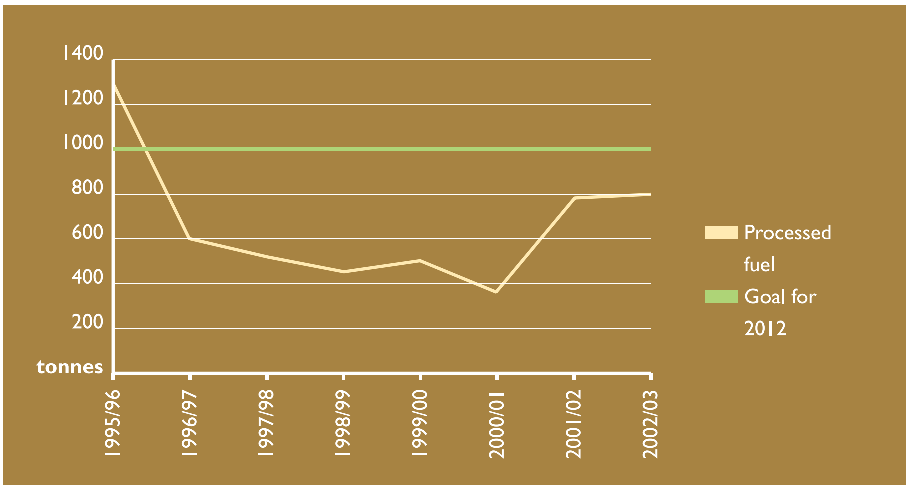
The plans for the new Thermal Oxide Reprocessing Plant (THORP) were made public for hearing by the British Ministry of the Environment in March in 1977. BNFL had already secured several contracts for the new facility (which the company expected to be up and operational in a relatively short time).
After about three months of hearings, approval to build the new plant was granted. However, construction took much longer than expected, and it was not until 1993 and after several costs overruns that THORP was finally completed. In the interim, the financial benefits of building the plant had melted away. Contrary to BNFL's expectations, the prices of uranium had not risen but had in fact fallen dramatically, such that the economic gains of extracting uranium from spent nuclear fuel were no longer so obvious. Simultaneously there were increasing concerns about the radioactive discharges, and a lawsuit concerning whether the plant was justified further delayed the opening of the facility until March 1994.

2.3.1 Technical information

THORP has an annual reprocessing capacity of 850 tHM/y, but production varies from year to year, depending on what kinds of contracts are secured from foreign countries. Like the Magnox reprocessing plant, THORP bases its technology on the Purex method.[23]
During its first years of operation, THORP experienced considerable difficulty in attaining planned production goals. This was primarily due to problems with one of the transfer systems for nuclear waste.[24] This in conjunction with other minor problems held production down, and in the entire time up to 2000, the plant had problems reprocessing enough fuel to reach the set goal of 7 000 tonnes of reprocessed fuel by April 2004.
By the close of 1998, THORP had reprocessed only 1 460 tonnes of fuel.[25] The year 2000 saw fewer operational problems, and THORP reprocessed its full capacity of

Reprocessed fuel in B205 in relation to goals.

*The figures for the fiscal year 2002/03 are preliminary calculations.



21 World Nuclear Industry Handbook 2003;
World Nuclear Industry Handbook 2003, page 220.
22 BNFL Press Release, 23.05.2000.

23 Nuclear Engineering International, 2003.
World Nuclear Industry Handbook 2003, page 220.
24 BNFL Annual Report & Accounts 1999: p. 24
25 BNFL Annual Report & Accounts 1998: p. 16

850 tonnes of fuel that year, setting a production record for the facility.[26] In November 2000 however, new technical problems had arisen, and the plant was again shut down for five months.

2.3.2 Economy

It cost 2.8 billion pounds to build THORP (£ 1993). This exceeded the original construction budget by a factor of three. It was however assumed that this amount would be recouped by income earned from the reprocessing of foreign fuel. BNFL expected the plant to realise profits of 50 million pounds annually, or 500 million pounds during the first ten years.[27] Yet even a profit of 500 million pounds would only cover 18 percent of the actual construction costs for THORP.

2.3.3 Contracts

When THORP began production in March 1994, BNFL had secured a certain number of so-called baseload contracts to reprocess about 7 000 tonnes of spent nuclear fuel. This was fuel that was to be reprocessed over the course of the facility's first ten years of operation. Over 4 000 tonnes of this fuel originated from foreign customers from eight different countries. The remaining contracts came from British clients.[28] Almost 90 percent of the contracts were signed more than ten years before the facility was completed, and a third of the foreign contracts were signed prior to 1976.

	1994 - 2004	Post 2004
Japan	2 676	
Germany	982	700
Switzerland	471	
Spain	169	
Italy	147	
The Netherlands	53	
Sweden	140	
United Kingdom	2 158	2 600
Total	6 796 tonnes	3 300 tonnes

Table 2: BNFL's contracts for THORP as of 1993 (Source: Berkhout, F., 1993 / 1997)

2.3.4 Delays

According to the original plan, BNFL was to have reprocessed all of the fuel covered under the baseload contracts by April 2004. However, technical problems have delayed reprocessing activities at THORP, and BNFL has been forced to admit that it will not be possible to reprocess all of the baseload contracts by the April 2004 deadline. Through negotiations with its baseload customers the company has been granted another year and has a new deadline of April 2005.

Several of the baseload contracts BNFL signed in the 1970s were so-called "open ended" contracts, meaning that BNFL could change the price of reprocessing in keeping with what it cost to handle the fuel. However, in that reprocessing spent nuclear fuel has become far more expensive than anyone could have anticipated. This kind of a contract is most disadvantageous for the customer. A number of companies therefore have accused BNFL of raising the prices as a consequence of its not having been able to maintain the reprocessing schedule specified in the contract. In May 2001, the British newspaper The Independent revealed that several companies from Germany, Japan, Switzerland, The Netherlands and Italy were threatening to break reprocessing contracts with THORP valued at six million pounds.[29] The parties eventually reached agreement for a temporary solution, but the conflict has recently flared up again.

Nor have the technical problems at THORP yet come to an end. In 2002 BNFL had to make comprehensive repairs to the facility, which in turn led to further delays in handling the customers' fuel.[30] In April 2003 and entering its tenth year of operations, THORP had not managed to reprocess more than 4500 tons of the 7000 tonnes that BNFL had committed itself to in its baseload contracts (these contracts account for 64 percent of the facility's contracts). Hence if THORP is to meet the terms of the agreements it has entered into, it must process more than 2000 tonnes of spent nuclear fuel within the next two years. However, with an annual maximum capacity of 850 tonnes a year, this will be practically impossible. Much of the fuel that awaits reprocessing has a higher burn-up than the fuel that was processed there before. This factor can cause further delays, not to mention problems of operating the facility within the permitted parameters for radioactive discharges (see chapter 8).

BNFL thus has some things to explain to its customers. At the same time, new threats are starting to come in from the company's German customers who are now considering buying their way out of the old contracts. One of these companies is Germany's largest nuclear company E.ON Energie AG. According to the journal Nuclear Fuel, German companies have discovered that it would be cheaper for them to take responsibility for their spent nuclear fuel themselves than to send it to Sellafield. If the contracts are cancelled, the German fuel will be stored in Germany prior to future disposal in a permanent repository there. Two other German power companies, RWE-AG and HEW-AG, bought their way out of similar contracts with Sellafield in the middle of the 1990s.[31]

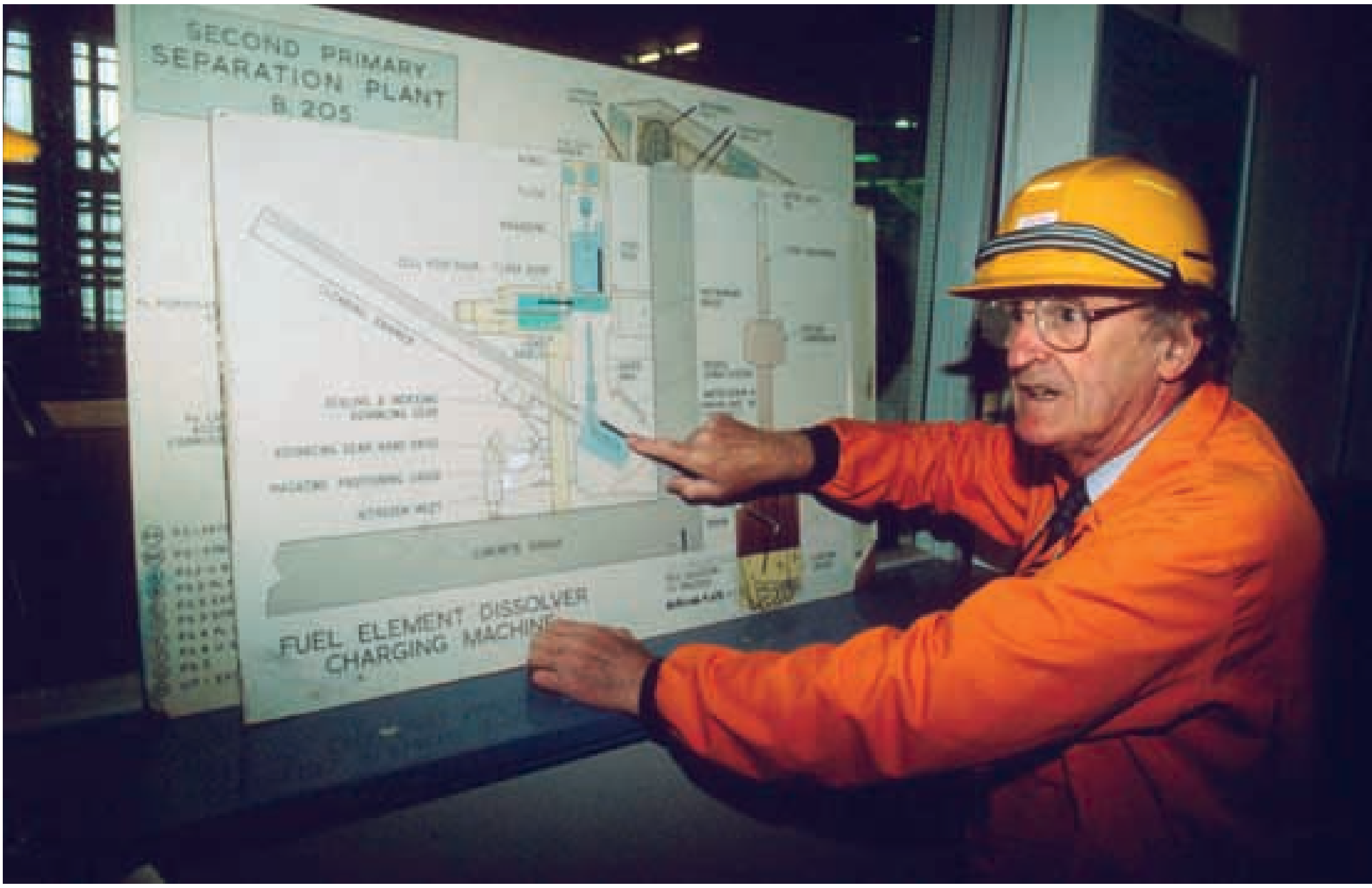
Furthermore, BNFL's largest reprocessing customer, British Energy, has signalled that it is considering ending reprocessing activities, and has expressed interest in an

26 BNFL Annual Report & Accounts 2000: p. 18
27 Greenpeace International, 1993: The THORP papers.
28 Forwood, M., 2001.
29 The Independent, 13.05.2001.
30 HM Nuclear Installations Inspectorate, March 2002: Sellafield Quarterly Report.
31 Nuclear Fuel, Vol. 28, No. 4, 17.02.2003.

agreement whereby BNFL stores British Energy's spent fuel at Sellafield only temporarily. The director of British Energy stated on an earlier occasion that his company considers reprocessing to be "economic nonsense".[32] British Energy has already built an intermediate storage facility to accommodate 2000 tonnes of spent AGR fuel, and currently stores all of the reactor fuel from the Torness power plant in Scotland.

Given the problems that BNFL has been experiencing in fulfilling its contracts, it has become extremely difficult for the company to secure new contracts for the next decade. In addition, the hopes of developing a plutonium-powered nuclear reactor (Fast Breeders) has been pushed 40 to 50 years into the future, if they even materialise at all. The contracts that BNFL has signed for the next decade have therefore been largely entered into with domestic customers.[33]

The present chairman of BNFL, Hugh R. Collum, has admitted that it looks doubtful that BNFL will be able to secure any new THORP contracts with German companies, and that they are preparing to examine alternatives to reprocessing.[34] Germany and Japan have



One of the veterans at the Sellafield facility, Phil Hindmarch, in the almost 40 year old B205 plant during a visit in 1998.

Table 3: Amounts of fuel reprocessed at THORP in relation to objectives (source: Forwood, M., 2001, 2003.)

*Annual goals have been estimated from the assumption that all fuel shall have been processed by April 2005. Up until fiscal year 2001/2002 the goal was that the fuel was to be processed by April 2004. Allowances have been made for this adjustment in the table.

32 The Independent, 14.05.2001.
33 BNFL, 1999: Annual Report & Accounts 1998, page 16.
34 The Independent, 31.03.2000.

been BNFL's largest customers outside Great Britain. The absence of contracts with these countries will make further operation of THORP almost impossible.

2.3.5 Decommissioning THORP

In 1992, BNFL estimated that it would cost 900 million pounds to decommission THORP. According to plan, THORP was to be decommissioned 50 years after the shutting down of the facility. This estimate is made from the starting point that the facility was to operated for 25 years and shut down before 2020.[35] The Germans shut down their pilot project in reprocessing at Karlsruhe (WAK) in 1991 and have estimated the costs of decommissioning to 600 million pounds.[36] WAK was much smaller than THORP with a capacity that was less than five percent that of the British facility.

35 BNFL, 1999: Annual Report & Accounts 1998, page 16.
36 The Independent, 31.03.2000.

Chapter 3
MOX production

MOX production

In December 2001, the world's largest facility for the production of Mixed Oxide Fuel (MOX) opened at Sellafield. MOX is a special kind of nuclear fuel that is made of new uranium and reprocessed plutonium. The Sellafield MOX Plant (SMP) is designed to produce 300 tonnes of MOX fuel a year. As of August 2003, SMP had yet to produce a single completed MOX fuel assembly. In addition to SMP, there is also a MOX research facility at Sellafield - the MOX Demonstration Facility (MDF).

3.1 MOX-Demonstration Facility (MDF)

BNFL first began to produce MOX fuel at Sellafield in 1993. It was manufactured in the MOX Demonstration Facility (MDF), a facility which today is only being used for purposes of research. However, in the 1990s, MOX fuel from MDF was delivered to customers in Switzerland and Germany.

In the autumn of 1999, an agreement was made to deliver MOX fuel from MDF to the Japanese company Kansai Electric Power Company. The first transport of MOX was transported by sea to Japan in July 1999. However, in September of the same year, it was discovered that the safety analyses for BNFL's MOX fuel had been falsified, and by December it became clear that this falsification also applied to the fuel that had been delivered to Japan. Consequently, Kansai Electric Power Company refused to utilise the fuel, and demanded that BNFL immediately take it back. At the same time the Japanese government issued a temporary moratorium on all business relations with BNFL.[37]

In March 2000, the Swiss Nuclear Safety Inspectorate (HSK) also complained about insufficient safety information about the MOX pellets in the fuel delivered by BNFL-Sellafield to Swiss customers. Prior to this, a weakness was discovered in some of the cladding of the MOX fuel delivered by BNFL to the Swiss Beznau reactor. In view of this defect, HSK forbade all import and use of MOX fuel from BNFL. Even before this, the country had instituted a moratorium against the export of fuel to Sellafield. HSK said that BNFL would have to show 'substantial improvements' before the moratorium could be lifted.[38]

When the scandal broke, British nuclear inspectors discovered that operators at MDF had been falsifying the safety analyses of the fuel since 1996. In a report from the Nuclear Installations Inspectorate (NII), it was stated that BNFL had 'a serious safety culture problem' and 'systematic management failure'.[39]

As a result of the scandal, Germany too prohibited any further import of MOX fuel from Sellafield. Like Switzerland, Germany had also instituted a moratorium on sending fuel to be reprocessed at Sellafield after German radiation authorities discovered elevated radiation values on the outside of BNFL's transport flasks.[40] Internally the scandal led to several dismissals, as well as a review of all the existing safety procedures. BNFL's chief executive, John Taylor, resigned his position.

In 1999, Sweden had plans to send 4.8 tonnes of spent reactor fuel from its first research reactor R1 to Sellafield for reprocessing. However, in the aftermath of the falsification scandal, the Swedish minister of the environment, Kjell Larsson, stated that a business deal with Sellafield would be 'very difficult, if not impossible' to justify[41]

In April 2001, Germany lifted its moratorium on reprocessing at Sellafield, and Switzerland followed suit in May.[42] Trade relations with Japan have also returned to normal after BNFL brought back the controversial MOX fuel the company had delivered to Kansai three years earlier. All commercial activity at MDF has ceased, and the facility is now utilised only for purposes of research.[43]

3.2 Sellafield MOX Plant (SMP)

In 1996, BNFL completed construction of the Sellafield MOX Plant (SMP), a new MOX factory with an annual production capacity of 300 tonnes of MOX fuel. The factory cost £482 million to realise. SMP first underwent a test period in which it produced ordinary uranium oxide fuel. By the end of 2000, the factory had produced 150 000 UO_2 pellets (one fuel rod consists of several such pellets). In 2001, BNFL was granted permission by British authorities to utilise plutonium oxide in order to manufacture MOX. Because SMP will utilise reprocessed uranium and plutonium from THORP in its production of MOX, the plant is important to future operations at the entire Sellafield plant.[44]

A number of experts are concerned that new MOX fuel can easily be utilised by terrorists to construct so-called "dirty bombs", and have consequently advised against granting the new MOX factory a licence. This conclusion was also reached in a report by Oxford Research Group, which was commissioned by the British Ministry of the Environment.[45]

An independent report commissioned by the British government shows that at best, SMP will earn only 216 of the 460 million pounds it cost to build the plant.[46]

The Irish government has vigorously protested against SMP and has brought two court cases against Great Britain in connection with the opening of the new plant. The first court case concerned Great Britain's responsibility under the terms of the OSPAR convention to inform neighbouring countries about this type of plant. Ireland claims that the British government had withheld information that was needed for an analysis as to the necessity of opening such a plant. Furthermore, Ireland

37 BBC News, 20.03.2000.
38 Greenpeace International, 17.04.2000.
39 The Daily Telegraph, 01.04.2001.
40 The Independent, 13.04.2001.
41 ENDS Daily March 1, 2000.
42 BNFL, 29.05.2001: Shipments of Nuclear Material between Switzerland and the UK.
43 BNFL Annual Report and Accounts 2000, pp. 18-19.
44 The Independent, 25.05.2001
45 The Guardian, 31.05.2001.
46 BNFL press release, 27.07.2001.

The village of Seascale, south of the Sellafield Plant.

charged that the plant was in violation of certain provisions in the UN Convention on the Law of the Sea (UNCLOS), pointing out that the increasing number of MOX fuel transports that will come with the plant constitute an unacceptable risk to the environment.

Both cases have been heard in the permanent court of arbitration at The Hague. While the court dismissed the first case in early July 2003, the second case is still under arbitration. Thus far in the process, the tribunal has criticised Great Britain for its lack of co-operation with Ireland concerning nuclear safety, and has ordered the two countries to work together more closely on safety.

3.2.1 Contracts

As of July 2003, BNFL had secured half the number of contracts needed to run SMP for the first ten years. The largest contract is with the German Power Company E.ON AG. BNFL believes that the contract with E.ON will make up 15 percent of SMP's capacity. According to Greenpeace, the E.ON contract entails converting 5.8 tonnes of German plutonium to MOX. As of today, German companies have 13.6 tonnes of plutonium stored at Sellafield.[47]

Two other contracts have also been negotiated, one with the Swedish concern OKG AB, the other with the Swiss power company Nordostschweizerische Kraftwerke AG. BNFL has yet to negotiate any MOX contracts with any Japanese companies. A new setback between BNFL and its Japanese customers occurred in the Spring of 2001 when citizens living near Japan's largest nuclear power plant voted in a referendum against the use of MOX fuel.[48]

47 The Guardian, 25.05.2002.
48 The Independent, 28.05.2001

The OKG AB contract

The Swedish OKG AB contract concerns 850 kg of Swedish plutonium that is being stored at Sellafield today. This plutonium is a product of Swedish nuclear fuel and was sent to Sellafield between 1975 and 1982. It was reprocessed as late as 1997.

Sweden altered its policy for handling spent reactor fuel in the middle of the 1980s, and no longer sends fuel to Sellafield. In 1996, the Swedish government went to great lengths to have the Swedish nuclear fuel returned to Sweden without having it reprocessed.[49] According to an exchange of letters between the British Health and Safety Executive (HSE) and the Swedish Nuclear Power Inspectorate (SKI) there were no technical or regulatory obstacles in the way to prevent the return of the fuel. However, negotiations to return the Swedish fuel stranded in 1997 when BNFL reprocessed the Swedish fuel, 140 tonnes in all. There is speculation as to whether BNFL did this to ensure itself future MOX contracts.

In December 2002 the Swedish government granted OKG AB permission to utilise MOX fuel in the Oskarshamn nuclear power plant. It is unknown when this fuel will be transported to Sweden.

Swiss contracts

The first MOX fuel to be produced at SMP will be sent to the Swiss Beznau nuclear power plant, a power plant that is owned and operated by Nordostschweizerische Kraftwerke AG and runs two Westinghouse pressurised water reactors.

Transports of Swiss MOX fuel will be sent from BNFL's pier in Workington, north of Sellafield. It is here that the fuel will be loaded on board the BNFL transport ship Atlantic Osprey. In contrast to BNFL's other vessels, Atlantic Osprey has only a single hull and no auxiliary motor in the event of the engine seizing up. Other transports by sea from Sellafield as a rule go from BNFL's private pier at Barrow, which is better equipped with respect to nuclear safety.[50]

49 Reuters, 22.02.1996.
50 Forwood, M., 2002: The Export of MOX Fuel to Switzerland.

Chapter 4
Historic discharges

Historic discharges

Since its opening in 1951, there have been substantial radioactive discharges to both the air and sea from Sellafield. The first discharges came with and were a direct result of the British nuclear weapons programme; exact information concerning the quantity and nature of these discharges is not available. The attitude of Prime Minister Clement Attlee when the first discharge pipe was built is very revealing: he wanted as little fuss as possible about the discharges, as this would draw attention towards the plant.[51]

It is the Department for Environment, Food and Rural Affairs (DEFRA) that issues the authorisations for radioactive discharges. Permits are granted under the guidelines of the Radioactive Substances Act of 1993 (RAS 1993). Sellafield has several licenses permitting discharges into the air, sea and on shore. The current discharge authorisation went into effect January 1, 1994, but has been revised several times since then. The most recent revision of radioactive discharges into air and water was made in November 1999, and went into effect on January 1, 2000. New limitations on radioactive discharges have been proposed and as of July 2003 were under discussion inside the department.

4.1 Radioactive discharges 1951-1964

Early in the 1950s, Great Britain carried out experiments in which large amounts of radioactivity were deliberately discharged into the Irish Sea. The purpose was to study the effect of all the different radioactive substances on the environment, as well as how they behaved in relation to each other. The lead scientist on the experiment, Dr. John Dunster, was a physicist at the UKAEA, and at the time he was in charge of Sellafield. In 1958, at the second UN conference concerning peaceful uses of nuclear energy, Dunster told UN delegates about the experiment:

"*The intention has been to discharge fairly substantial amounts of radioactivity … the aims of this experiment would have been defeated if the level of radioactivity discharged had been kept to a minimum.*"[52]

He continued, explaining that the discharges had been:

"*… high enough to obtain detectable levels in samples of fish, seaweed and shore sand, and the experiment is still proceeding. In 1956 the rate of discharge of radioactivity was deliberately increased, partly to dispose of unwanted waste, but principally to yield better experimental data.*"

In more recent years, it has become clear that the experiment started in May 1952 and continued well into the decade. In the mid of the 1980s, Dunster became director of the National Radiological Protection Board (NRPB), which is the national authority that advises on maximum permissible radiation doses to the British population.

4.2 The Windscale fire in 1957

In the early morning of October 10, 1957, the operators at Windscale Pile No.1 began work to release the energy that had accumulated in the graphite of the reactor (Wigner energy). In that the bombardment of neutrons within the reactor caused large amounts of energy to accumulate in the form of heat inside the graphite, this was a normal procedure that needed to be regularly performed. Otherwise the build-up of heat within the graphite would eventually start a fire.

The exact reason for the fire is still not known, but the most probable cause appears to be that the operators did not perform the routine procedure with sufficient care. Furthermore there were no good safety procedures governing how the operation should be executed. The reactor was completely ablaze before the alarm sounded. The operators tried to draw out the reactor's fuel elements but the operation took too long. The result was an extensive fire inside the reactor core, which lasted for more than 24 hours.[53]

The fire led to two major releases of radioactivity to the air. The first large release occurred when the natural uranium inside the reactor core caught fire. The second occurred early on Friday, October 11, when the reactor was showered with water in an attempt to extinguish the fire. A huge cloud of steam transported radioactive particles and gases up into the air. The radioactive cloud drifted southwards, over most of England, and continued over Europe. At about 11 a.m. the same day, the fire was under control. Over 20 percent of the reactor core were damaged in the fire.[54] Workers at the Sellafield facility itself were exposed to radiation doses 150 times higher than the prescribed dose limit, while certain individuals among the local inhabitants were exposed to radiation doses 10 times higher than the maximum lifetime doses. Though UKAEA knew about the high radiation levels, it was nevertheless decided not to evacuate the population.[55]

The day after the fire, the authorities halted the distribution of milk from 17 farms in the district, and on October 12, the Medical Research Council ruled that milk containing more than 3 700 Bq per litre should not be used. It was assumed that this limit would affect all milk production in an area of approximately 500 km^2; consequently, all milk from this entire area was recalled. The activity measured in one of the milk samples was as high as 50 000 Bq per litre, coming from a farm located 15 kilometres away from the reactor. Iodine absorption

51 Berkhout, F., 1991, page 140.
52 May, J., 1990, page 119.

53 May, J., 1990, page 116.
54 The Daily Telegraph, 01.01 1988.
55 May, J., 1990, page 116.

Information about the Windscale fire in 1957 was kept secret until 1988.

to the pancreas was also observed, with the highest measured dose estimated to be 160 mGy.[56]
However, three days after the drastic measures went into effect, it was discovered that some of the milk produced outside the most exposed area was also contaminated with iodine-137. Milk samples taken from a farm in Grasmere in the Lake District showed concentrations of between 4 400 Bq per litre and 6 600 Bq per litre. Yet despite these discoveries, the milk was nevertheless distributed to the market. The papers documenting these figures were classified by the government so as to avoid "unnecessarily alarming" the population.[57]
The majority of the restrictions on milk distribution were lifted on November 4 in the same year, while the remaining restrictions were cancelled on November 23, only about a month after the accident.[58] In all, about two million litres of milk containing iodine-131 were dumped into the ocean or nearby rivers.[59]
Efforts have been made to estimate the extent of the radioactive releases. It is believed that the accident led to a release of between 600 and 1,000 TBq of iodine-131, between 444 and 596 TBq of tellurium-132, between 22.2 and 45.5 TBq of caesium-137 and about 0.2 TBq of strontium-90.[60]
The British Prime Minister at the time, Harold MacMillan, suppressed all technical information concerning the accident. He feared that the conclusions of the accident report - that the accident occurred as a consequence of operator negligence and poor instrumentation, as well as the report's reference to an earlier accident in 1952 - would adversely affect the people's confidence in the nuclear energy programme, and postpone the develop-

56 May, J., 1990, page 116.
57 The Daily Telegraph, 01.01 1988.
58 May, J., 1990, page 116.
59 Arnold, L., 1992, page 61. Henriksen, T., 1993, page 114.
60 May, J., 1990, page 116
61 Arnold, L., 1992, page. 185. Henriksen, T., 1993: p. 114.

Every day millions of litres of radioactive waste is discharged through this pipeline at Sellafield.

ment of British nuclear weapons. Macmillan declared that complete openness about the accident would jeopardise national security.[61]

It was 25 years before official estimates of the accident's effects on the health of local inhabitants were made public. In 1982, the British National Radiological Protection Board issued a report describing the full truth about the Windscale accident. It was estimated that 32 deaths and at least 260 cases of cancer could be attributed to the fire.[62] However, independent experts maintain that the fire in actual fact led to over a thousand deaths.[63]

In an attempt to prevent negative associations with the plant, UKAEA changed the name of the plant from Windscale to Sellafield after the accident - a name that today carries just as many negative connotations as its predecessor did.

4.3 Discharges in the period 1964-1990

In the 1960s and 70s radioactive discharges from Sellafield increased dramatically. The main reason for this was the discharges of alpha activity originating from a new reprocessing plant (B205) that UKAEA had opened in 1964. This facility was twice the size of the B204 plant, and at the time was producing weapons-grade plutonium. The term alpha activity discharges is a collective term for discharges of radionuclides that release alpha radiation such as plutonium and americum-241, for example. These substances are highly radiotoxic, and consumption of even a tiny amount can be lethal.

In the mid 1960s, the discharges of radiation increased so dramatically that UKAEA, which was running the plant at the time, had to apply for permission to discharge alpha activity in excess of the 66.6 TBq per year that had been originally established. In addition to the discharges from the reprocessing plant, discharges of radiation from the fuel storage also added to the high discharges. Furthermore, in the 1960s and 70s, the coolant water from the fuel reservoir was pumped straight into the sea.

61 The Daily Telegraph, 01.01.1988.
62 May, J., 1990.
63 Berkhout, F., 1991: pp. 148-149.

4.3.1 The formation of BNFL and the introduction of discharge monitoring

In the time that Sellafield was a military facility, there was no monitoring of discharges. In principle, an increase of unmonitored discharges was permitted until 1971 when BNFL was formed and assumed responsibility for running the reprocessing facility. However, even when formal monitoring was introduced, it did not necessarily lead to actual monitoring of radiation releases in practice. All limitations governing the permitted amounts of radioactive discharge from the facility were in reality a result of negotiations between BNFL and the government and were never formally written down in a formal discharge permit.[64] Nor was there any specific discharging limits for the individual nuclides, but instead a sort of "blanket permit" that established certain limits for the total alpha and beta discharges, but no limits for the individual nuclides. In a period where the discharges might be low for one given nuclide meant that one could thereby increase the discharges of the other nuclides with the same properties. However, after 1970, specific restrictions on strontium-90 and ruthenium-106 were introduced.[65] Discharges of transuranic elements such as plutonium were not monitored until 1973. These were discharges that were covered in theory by the discharge permit, but which in practice were never monitored. Full monitoring of radioactive discharges from the facility was not introduced until the Site Ion Exchange Plant (SIXEP) purification facility was installed in 1984.[66] The purpose of SIXEP is to cleanse the cooling water in the storage pools for spent nuclear fuel.

4.3.2 Discharges in the 1970s

By 1970, British authorities had granted UKAEA a permit to increase the limit for such highly radiotoxic alpha emitters as plutonium-239 and americium-241 by almost 350 percent, from 66 TBq to 222 TBq.[67] When BNFL took over the plant, the total radioactive alpha discharges were running at almost 100 TBq a year. On an annual basis Sellafield was releasing over 50 TBq of plutonium, along with almost 6 000 TBq of beta emitters in addition.[68] Yet one of BNFL's first acts after taking over the plant was apply for permission to increase the discharges even further. Originally the department desired to limit the discharges of caesium-137 to 370 TBq per quarter, but after intense lobbying from BNFL, the authorities consented to increase the upper limit to 555 TBq per quarter. The reason given was the tremendous corrosion problems BNFL were experiencing with spent Magnox fuel; furthermore it would be extremely expensive to reduce the high caesium discharges.[69]

In the middle of the 1970s the radioactive discharges from the plant reached their peak. In the five-year period from 1974 to 1978, Sellafield released more than 40,000 TBq of beta emitters. From 1968 to 1978, the plant is believed to have released almost 1000 TBq of alpha emitters. In 1973 alone, the plant released over 180 TBq of alpha emitters.[70] Compared to the French reprocessing plant at La Hague, Sellafield in this period exceeded the French facility's releases of beta emitters by a factor of eight and the highly radiotoxic alpha emitters by as much as 200 times more.[71]

The discharges of caesium-137 and plutonium were also exceedingly high in the 1970s. In the years from 1974 to 1978 the annual discharges of caesium-137 from the facility were well over 4 000 TBq. The discharges of plutonium in the same period were between 45 and 60 TBq a year - also very high figures.[72] Over the course of these five years, doubly the amount of plutonium was discharged from Sellafield as was released during the Chernobyl accident of 1986 in which approximately 100 TBq of plutonium was discharged.[73]

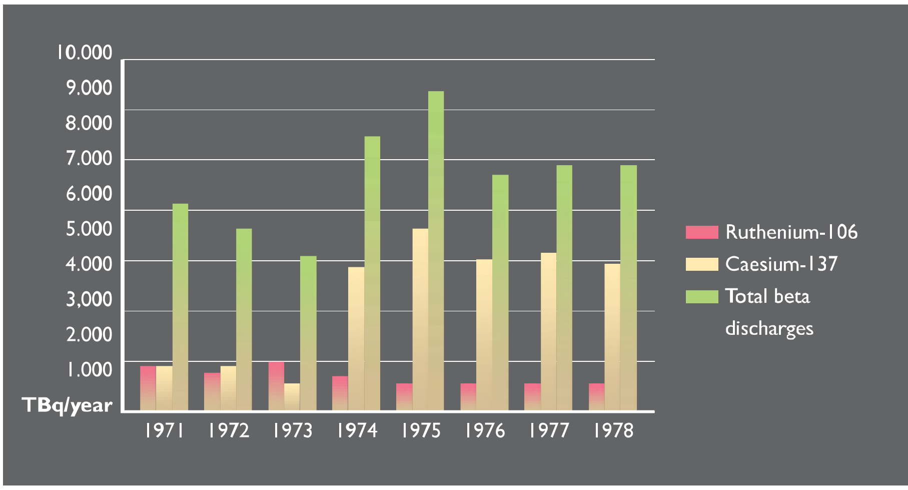
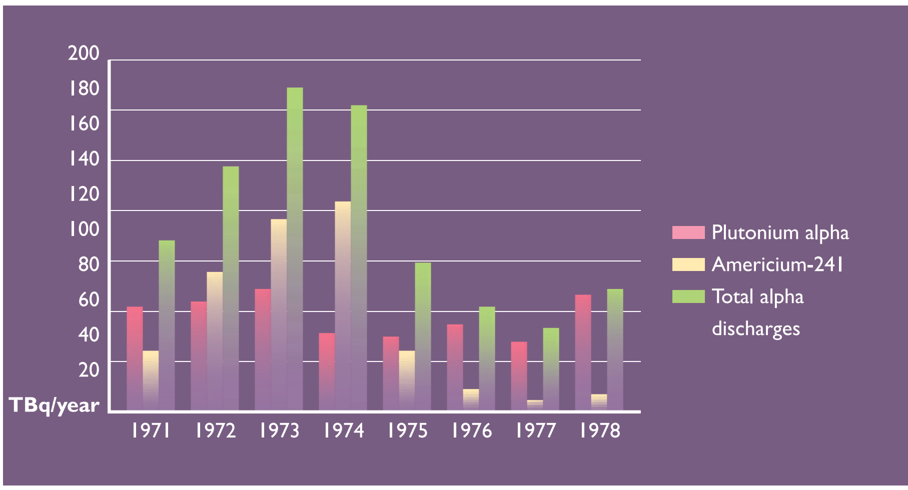


Table 4
Beta discharges from Sellafield in the period 1971 to 1978.

Table 5
Alpha discharges from Sellafield in the period 1971 to 1978.



64 Sumner, D., *et al.*, 2000, page 415.
65 Ibid, page 416.
66 Berkhout, F., 1991, page 150.
67 Bunyard, P., 1986: The Sellafield Discharges.
68 BNFL 2000: Annual Report on Discharges and Monitoring of the Environment 1999, page 29.
69 Bunyard, P., 1986: The Sellafield Discharges.
70 BNFL 2000: Annual Report on Discharges and Monitoring of the Environment 1999, page 29.
71 Bunyard, P., 1986: The Sellafield Discharges.
72 BNFL 2000: Annual Report on Discharges and Monitoring of the Environment 1999, page 29.
73 AMAP, 1997, page 114.

Following an operational error in 1983, 20 kilometres of the shoreline outside Sellafield had to be closed off due to radioactive contamination.

By the close of the 1970s, the discharges of technetium-99 (Tc-99) were also high. In the three-year period from 1978 to 1980, Sellafield released nearly 300 TBq of Tc-99. However, throughout the 1980s, much of the liquid waste from the Magnox plant was stored in large pools on land, and the discharges of Tc-99 fell drastically to about 6 TBq a year. Discharges remained at this level until 1994 when BNFL began to discharge the stored waste, at which point the discharges exceeded the figures from the 1970s (see Chapter 7).

4.3.3 Discharges in the 1980s

Even though discharges from the Sellafield facility were dramatically reduced at the beginning of the 1980s, the plant nevertheless remained Europe's worst nuclear polluter - despite BNFL having dealt with the most serious corrosion problems related to spent nuclear fuel.[74] In 1984, 90 percent of the British population's annual radiation dose from nuclear facilities was attributable to Sellafield. This figure fell to 60 percent in 1987.[75]

On November 18, 1983 an accident in BNFL's Magnox reprocessing facility led to uncontrolled discharges of large amounts of radioactivity to the sea. The discharge spread along the coast and contaminated the beaches in the area. The radioactivity in seaweed along the coastline was discovered to be so high that the Department for Environment, Food and Rural Affairs (DEFRA) decided to cordon off over 20 kilometres of the shoreline. A major effort to clean up the beaches began, and restrictions on using the beaches remained in effect until the following summer. The authorities maintained that they had not been informed of the accident until a week after it had happened. Following a police investigation of the case, BNFL was fined £10,000 and also had to pay legal costs amounting to £60,000.[76]

In the early 1980s, British researchers discovered that the plutonium content in shellfish from off the coast of Sellafield was five times higher than normal. As a result, the radiation contribution from plutonium to the so-called "critical group" (the population group considered to be most exposed to radiation doses resulting from the Sellafield discharges) was adjusted by a factor of 15. In 1984 the British Waste Management Advisory Committee asserted that the population living in certain areas close to Sellafield, by mere means of their food intake alone would receive 69 percent of the critical dose limits as established by the International Commission on Radiological Protection (ICRP). Furthermore, researchers in the Department of Environmental Studies maintained that the population in the local vicinity of Sellafield area was also being exposed to radiation through fission products washed ashore. They estimated that 45 percent of the total amount of radiotoxic alpha emitters released in the period 1968 to 1978 were americium-241 which was washed up on the beaches with the tidewater in fine sand and other sediments, or else in the form of sea mist which the population might then inhale.[77]

As a consequence of the discharges, the entire coastline from Maryport in the north to Wyre in the south was badly contaminated by americium-241. The same researchers learned that plutonium had a greater ability to bind to organic material on the bottom of the sea than was previously believed. Hence plutonium could reach humans more easily through the food chain than if it remained undisturbed in non-organic sediments. In view of these new findings, BNFL announced that it would spend £10 million to reduce the discharges of plutonium and americium from 37 TBq per year to about 7 TBq per year.

The largest discharge reduction measures came in the mid 1980s, when BNFL installed a new cleansing plant, the Salt Evaporator and Site Ion Exchange Effluent Plant (SIXEP). Discharges of beta-emitters, among other substances, then fell from about 575 TBq in 1985 to about 50 TBq in 1992.

4.4 Discharges in the last ten years

Discharges from Sellafield in more recent years originate mainly from the reprocessing plants THORP and B205. In addition, there are radioactive discharges connected to decommissioning work in progress in the area and

74 Bunyard, P., 1986: The Sellafield Discharges.
75 Sumner, D. *et al*, 2000, page 417.
76 Berkhout, F., 1991, page. 171.
77 Bunyard, P., 1986: The Sellafield Discharges.

from the storage facilities for spent reactor fuel. The large amounts of radioactivity remaining after reprocessing activities are now largely handled at a separate purification plant on the site (EARP). Discharges from the storage pools for spent reactor fuel are purified in a separate plant (SIXEP). However, it is both difficult and expensive to eliminate all radioactivity. For example, none of the plants are capable of removing the radioactive substance technetium-99, which is a waste product from reprocessing. These isotopes are consequently discharged directly into the Irish Sea.

High-level liquid waste left over from reprocessing is vitrified and stored at the facility. Some of the intermediate-level liquid wastes are also treated before being discharged into the sea. Coolant water from the storage facilities for Magnox fuel is cleansed of caesium-137 and strontium-90. Low-level liquid wastes are simply discharged untreated through a pipe directly into the sea.[78]

With the opening of the new THORP reprocessing facility, BNFL also installed a new purification plant, the Enhanced Actinide Removal Plant (EARP). Since this plant entered operation in 1994, discharges of both alpha and beta activity have decreased. The total alpha discharges from Sellafield have fallen from 400 GBq in 1995 to 120 GBq in 1999.[79]

In addition to the discharges mentioned above, there are discharges from the plant's sewage pipes, which drain directly into the sea. In 2000, these discharges consisted respectively of 0.035 GBq of alpha particles and 0.49 GBq of beta particles.[80] These discharges are expected to increase slightly when the system of pipelines is adjusted to drain more rainwater from a larger area of the facility site directly into the sewer.

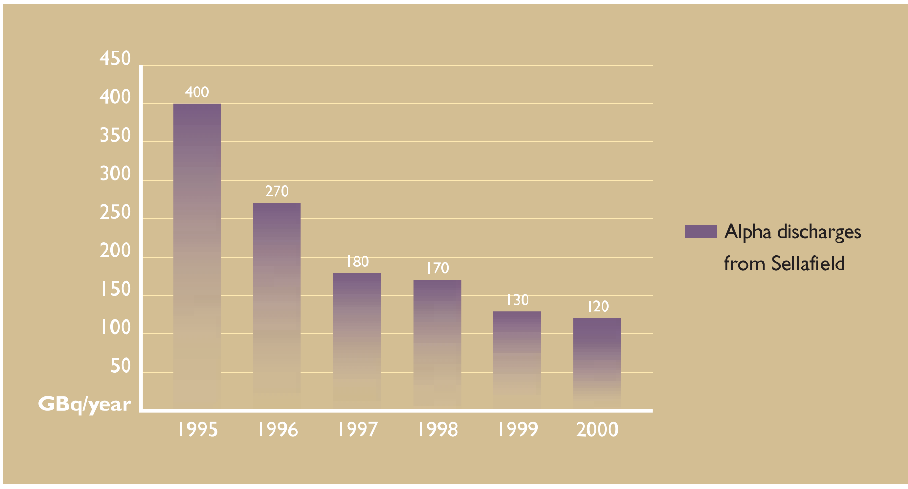


Table 6
Discharges of alpha radiation from Sellafield, measured in GBq.

Table 7
Discharges of beta radiation from Sellafield, measured in TBq.

78 Ibid.
79 BNFL, 2001: Annual Report on Discharges and Monitoring of the Environment in the UK, 2000, page 23.
80 Ibid, page 25.

Chapter 5
Aerial discharges

Aerial discharges

Several of the different plants at Sellafield release radioactive effluents to the atmosphere. The most major discharges come from the ventilation systems at THORP which releases tritium, carbon-14, krypton-85, strontium-90, ruthenium-106, iodine-129, caesium-137, americium-241 and argon-41 as well as small amounts of plutonium.

The Environment Agency (EA) has made a three year review of the collective discharges from Sellafield, and in August 2002 presented its proposal for new discharge limits. As of December 2003, the new proposal was still under discussion in the Ministry of Health and at the Department for Environment, Food and Rural Affairs (DEFRA).

In EA's proposal for new discharge limits, several of the limits have been adjusted upwards compared to the original proposal that had been sent out for hearing in the fall of 2001. In this most recent proposal, BNFL has managed to negotiate higher limits both for the total alpha discharges and total beta discharges to the air. The current proposed discharge limits are now respectively 76 and 68 percent higher than they were in the proposal considered in the hearings. In addition, EA has removed the discharge limits for cobalt-60. In the proposal submitted to the hearing committees, the discharge limits lay far below the figures that will now be implemented. This may have weakened the democratic process in the handling of the matter. BNFL has thereby come out of the hearings victorious and won support for its request for a much higher ceiling on discharges than was originally proposed.

The following radionuclides have higher discharge ceilings that was originally proposed (percentages higher): strontium-90 (4%); ruthenium-106 (100%); antimon-125 (64%); caesium-137 (4%); plutonium-alpha (19%); plutonium-241 (3%); americium-241 and curium-241 (9%).[81]

5.1 Discharges from THORP

Some of the largest discharges from Sellafield come from THORP. However, the annual discharges from THORP depend on how much nuclear fuel is treated. This is especially true for discharges of radioactive tritium (H-3). The present discharge permit for tritium from THORP is set at 33 TBq/year. This permit was granted by DEFRA and took effect January 17, 1994. The permit is based on processing between 400 and 8000 tonnes of fuel.[82] If more fuel is reprocessed, the permit is for 43 TBq a year, while for amounts of 100-400 tonnes of reprocessed fuel, the discharge limit is 22 TBq a year.[83]

So far, BNFL has managed to keep the discharges within the limitations of the permits, but this is largely due to the fact that THORP has not processed as much nuclear fuel as was expected. With the new goals to reprocess more than 1000 tonnes of fuel a year, it may be difficult to stay within the limits. Furthermore, much of the fuel that will be reprocessed in the next few years has a higher burn-up and a shorter cooling time than the fuel that was processed at THORP before; hence this could lead to increased discharges.

BNFL projections for future discharges indicate that the

Radionuclide	Present limit (GBq/year)	Proposed limit (GBq/year)	Proposed reduction in limit (%)
H-3	1 500 000	1 100 000	27
C-14	7 300	3 300	55
S-35	210	210	0
Ar-41	3 700 000	1 600 000	57
Co-60	0.92	No limit	-
Kr-85	590 000 000	440 000 000	25.5
Sr-90	9.4	0.71	92
Ru-106	56	28	50
Sb-125	5	2.3	54
I-129	70	70	0
I-131	55	55	0
Cs-137	18	5.8	68
Pu-alpha	1.2	0.19	84
Pu-241	17	3	82
Am-241 + Cm-242	0.74	0.12	84
Total alpha	**2.5**	**0.88**	**65**
Total beta	**340**	**42**	**88**

Table 8: Current discharge permits from Sellafield to the air and proposed changes from EA (Source: EA 2002).

81 Environment Agency, 2001 / 2002, in Amundsen, I., *et al*, 2003.
82 BNFL, 2001: Discharge and Monitoring of the Environment in the UK 2000, page 26.
83 Forwood, M., 2001.

Annual discharges from Sellafield depend on how much nuclear fuel is processed at THORP.

company may have problems staying within the boundaries of the discharge permits. BNFL is planning a large increase in its tritium discharges in the coming years and has stated on several occasions that the existing discharge limits are too strict. If BFNL is to remain within the boundaries of its discharge permits, it would appear that it would have to reprocess less fuel than originally planned, thereby further irritating already exasperated customers. The alternative is to violate the established discharge limits.

In EA's most recent discharge assessment for Sellafield, one of the proposals is to lower the discharge limits for Ru-106 from THORP from 50 GBq/year to 37 GBq/year. According to BNFL, this step could have the effect of preventing the company from achieving the reprocessing targets it has set for itself. BNFL writes, "There is a risk that this could constrain future THORP's business as there is a high degree of uncertainty in Ru-106 projections due to its relatively short half-life (extreme sensitivity to fuel cooling variations) and the current lack of experience in processing burn-up/short cooled fuels through THORP." BNFL writes further, "Any further limit reductions at this time would clearly not be appropriate."

Earlier discharge estimates from THORP were made on the basis of fuel that had been standing in coolant for up to twelve years. In the coming years BNFL will reprocess fuel that has only had a five year cooling period and which has a much higher burn-up than the fuel the company has handled before. This too could lead to higher discharges.[84]

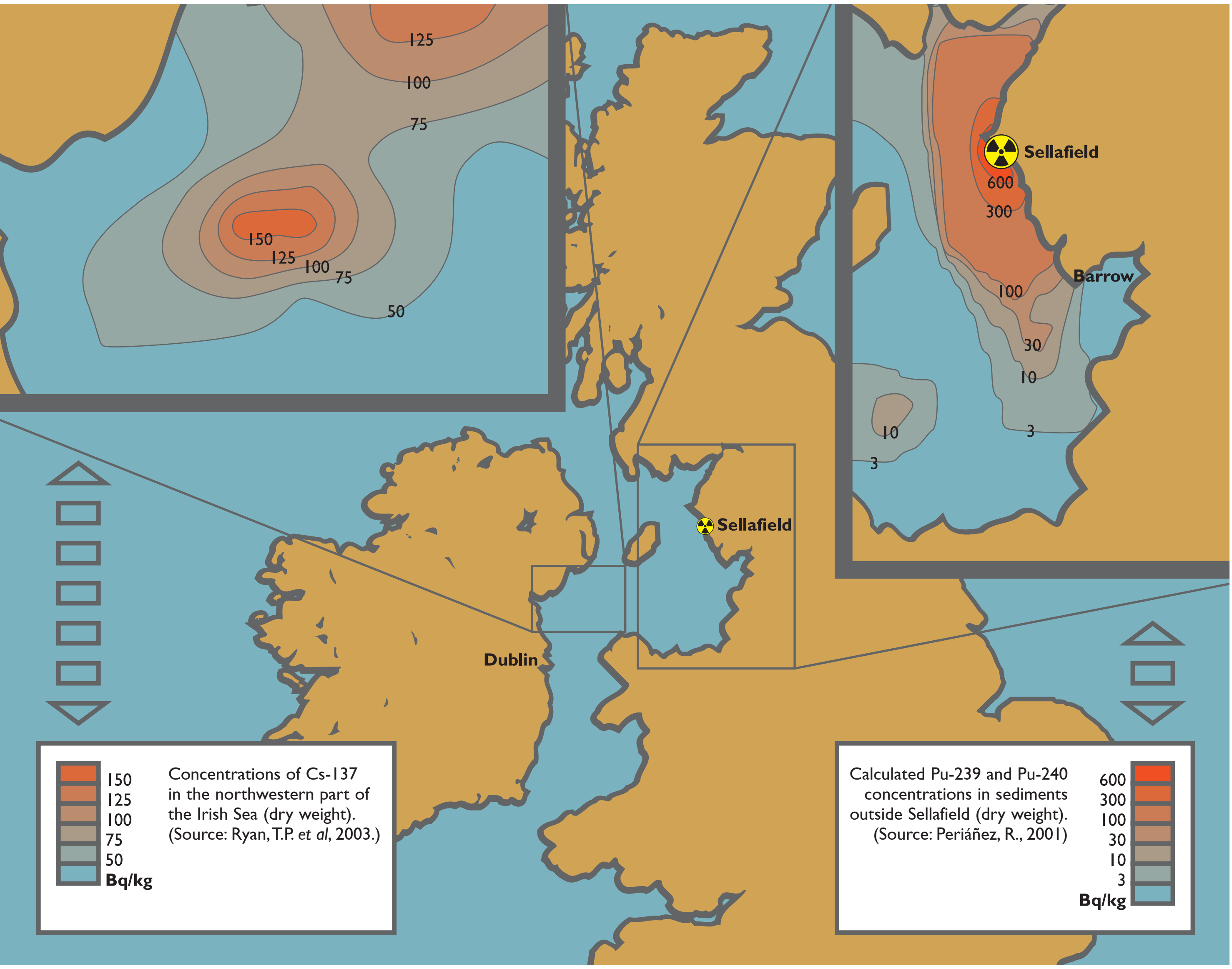
84 BNFL 2000: Review of discharges and disposal of radioactive waste, pp. 10-11.

Chapter 6
Radioactive contamination

Radioactive contamination

The radioactivity that is released from Sellafield is transmitted to the natural environment in the entire Irish Sea. Radioactive isotopes released from Sellafield may be found in larger or smaller concentrations both in seafood such as fish, shellfish and crabs, as well as in other parts of the natural environment such as seawater, sediments and in the grass onshore. Concentrations of radioactivity in the marine environment for the most part reflect discharges to the sea, while concentrations of radioactivity onshore may be largely attributed to releases of radioactivity to the air. However, there is some overlap as radionuclides can be transported from the sea to land with tidewater motions, sea mist and other sea-to-shore processes. Concentrations of plutonium, caesium-137 and americium-241 are mostly due to historical discharges.[85]

Environment Agency has its own monitoring programme for radioactive waste in the environs surrounding Sellafield. Part of this programme includes taking measurements of radioactivity along beaches in Cumbria, in the seawater along the coast, as well as in rivers and lakes further inland. Calculations are also made of radiation doses to people walking along the beaches.
Another monitoring programme is being carried out by the British Food Standards Agency (FSA) in co-operation with the Scottish Environment Protections Agency (SEPA). This programme tracks radioactive contamination in plants and animals both on land and in the water in the area around the Sellafield facility. In addition, BNFL has its own monitoring programme. This chapter endeavours to summarise the information from the different monitoring programmes.



Concentrations of Cs-137 in the northwestern part of the Irish Sea (dry weight). (Source: Ryan, T.P. *et al*, 2003.)

Calculated Pu-239 and Pu-240 concentrations in sediments outside Sellafield (dry weight). (Source: Periáñez, R., 2001)

85 BNFL, 2000: Discharges and Monitoring of the Environment in the UK. Annual Report.

6.1
The Irish Sea

Radioactive releases to the sea from Sellafield end up in the Irish Sea. The Irish Sea is the 2400 km^2 body of sea between England and Ireland. It is partially enclosed with openings respectively only to the south and the north out to the English Channel and the North Atlantic. The fact that this body of seawater is partially enclosed prevents the circulation of the water masses - and this in turn reduces the effective amount of "fresh" water available to dilute the discharges of radioactivity in the Irish Sea. Over the course of the summer months, a relatively closed circulation is created, while the circulation increases somewhat during the winter months.[86]

The Irish Sea today is the world's most radioactively contaminated marine area.[87] According to the Quality Status Report (QSR) for 2000 from OSPAR (a convention for the protection of the environment in the north-east Atlantic), the Irish Sea is polluted by about 200 kilograms of plutonium.[88] Traces of artificial radioactive substances may be found throughout the Irish Sea, increasing in concentration the closer to the Sellafield facility the samples are taken. The levels of caesium-137 in the seawater vary from approximately 500 Bq/m^3 in the vicinity of the effluent pipes to 2 Bq/m^3 in the open sea. Caesium-137 is the artificial radionuclide that constitutes the principle source of human exposure to radiation. In terms of human exposure to artificial radioactive elements, the most exposed population group in Ireland receives 60-70 percent of its radiation exposure from caesium-137 originating from activities at Sellafield.[90] For areas in the vicinity of Sellafield however, other radionuclides such as technetium-99, plutonium-239, plutonium-240 and americium-241 play a more significant role with respect to radiation doses to the most exposed population group.[91]

It remains uncertain what kind of ecological impact this kind of radioactive contamination can have on the environment. Here is what appeared on the matter in the OSPAR Quality Status Report:

"*The interest in the behaviour of radionuclides in the marine environment has, until now been driven by the objective of protecting human health from ionising radiation through the food chain. While the system of human radiological protection has been well developed through the adoption of internationally recognised guidelines and standards, there are currently no internationally accepted radiological criteria for the protection of marine flora and fauna. The assumption has been that man is the most radiosensitive organism and that if man is adequately protected, then other living things are also likely to be sufficiently protected.*"[92]

In more recent years there has been a greater recognition that radioactive contamination can harm the environment, even if it does not initially harm human beings. Today there is growing agreement that the environment needs its own protection. The International Atomic Energy Authority (IAEA) now acknowledges the following:

"*There is a growing need to examine methods to explicitly address the protection of the marine environment from radiation. The concept of sustainable development places environmental protection on the equal footing with human protection, on the basis that it is necessary first to protect the environment in order to protect human populations*" *(IAEA 1999).*[93]

6.2
Diffusion

The various radioactive substances that are discharged from Sellafield diffuse in the environment to different degrees. Of all the radioactive decomposition products that are released from the facility, technetium-99 (Tc-99) is one of the most mobile substances. Tc-99 spreads rapidly with the currents of the ocean: from the time that the element is released from Sellafield, it takes only five months for the element to reach the coast of Ireland. The discharge takes nine months to spread to the North Sea, and about 2.5 years to reach the Norwegian coast. The discharges reach the Barents Sea in approximately six years, but by that time the concentration has been considerably reduced.

In 2000, concentrations of Tc-99 in the seawater just off the Sellafield facility were measured at 25 Bq/m^3.[94] For measurements taken along the Norwegian coast in the same year, the average concentration was 1.3 Bq/m^3, while in the North Sea, the concentration of Tc-99 varied from 0.22 Bq/m^3 to 7.3 Bq/m^3.[95]

Heavier radioactive elements such as plutonium and caesium-137 sink for the most part to the bottom of the Irish Sea. It is estimated that 85 percent of all plutonium that is released from Sellafield is lying in the sediments along the coast just off the facility. However, even if these substances do sink to the floor of the Irish Sea, they still spread in the environment, in part through the mobility of the sediments. This means that the sediments do not lie stable on the ocean floor, but tend to drift. Irish studies show that the sediments have a tendency to drift in a southwesterly direction towards Ireland.

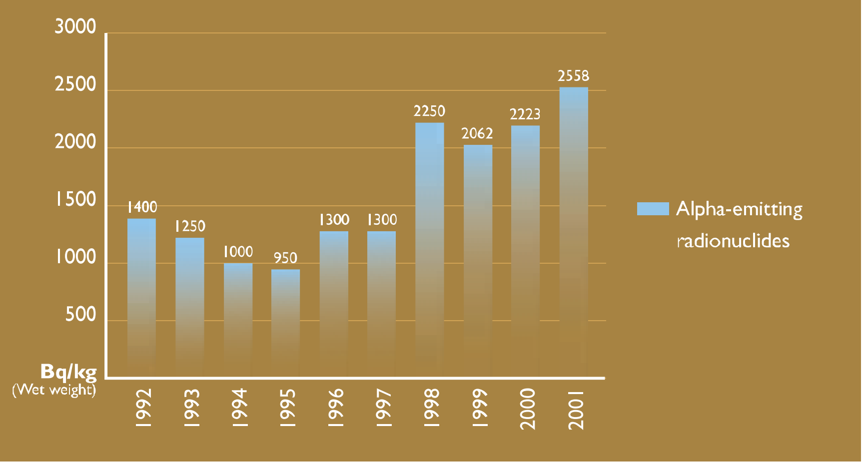
The heavier radioactive substances from Sellafield also contaminate Scottish fjords. In the summer of 2003, an Irish research team reported high measurements for plutonium in the Scottish fjords Solway and Esk. The samples were taken the year before, and showed so-called "hot spots" of plutonium and americium-241

86 Hartnett, M., 2003, Appendix 7.
87 Nies, H. *et al*, 1999.
88 OSPAR, 2000, para 4.9.3.
89 OSPAR, 2000, para 4.9.2.
90 Ryan, T.P. *et al*, 2003.
91 OSPAR, 2000, para 4.9.5.
92 OSPAR, 2000, para 5.3.1.3.

93 OSPAR, 2000, para 5.3.1.3.
94 BNFL, 2001: Discharges and monitoring of the environment 2000, page 35.
95 Kolstad, A.K., *et al*., 2002, page 9.

(Am-241). Some measurements showed figures as high as 15,000 Bq/kg of Am-241 and Pu. These were much higher values than the Scottish Environmental Protection Agency had been able to assert before. The Irish research team had taken samples 80 cm down into the sediments and in this way had obtained different results than SEPA who had taken samples from the surface of the ocean floor.[96]

Table 9
Total amounts of alpha-emitting radionuclides in sediments in West Cumbria (Newbiggin). Average values (Source: Environment Agency 1999, 2000, 2001).



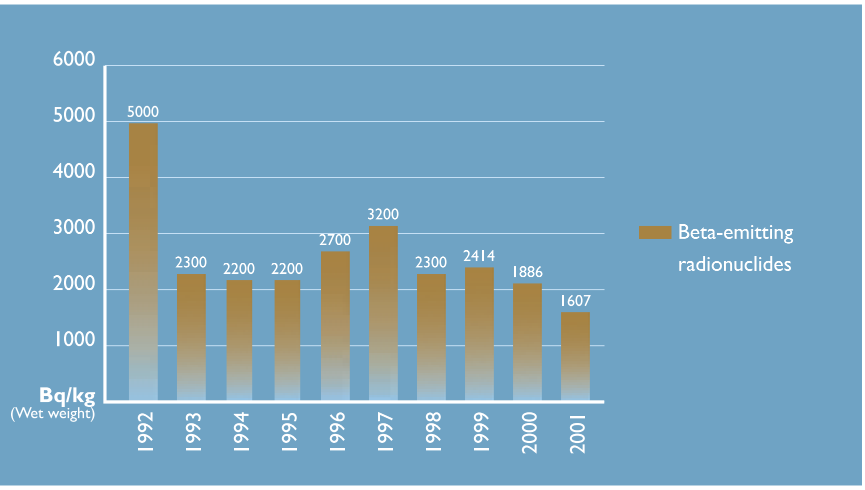
In the Barents Sea, plutonium concentrations of 12.8 millibecquerel/kg have been measured. The primary source of plutonium contamination in the Barents Sea is the fallout from nuclear testing, but the Norwegian Radiation Protection Authority does not rule out the possibility that traces of plutonium might also originate from Sellafield.[97]

6.3 Sediments and sand samples

Both BNFL and the Environment Agency take routine samples of the sand and sediments along the beaches of the Cumbria district in Northwest England in which Sellafield is located. However, EA presents better numerical documentation than BNFL. Table 9 shows concentrations of alpha-emitting radionuclides in the sediments in Newbiggin, a few kilometres south of the Sellafield facility. Table 9 shows that the concentrations of alpha-emitting radioactive contamination along this beach have more than doubled since the beginning of the 1990s. Furthermore, figures from EA show that this is not an isolated event, but that the concentrations of alpha-emitting radionuclides are steadily increasing all along the Cumbrian coast. From 1999 to 2001, the concentrations of radioactive alpha-emitting radioactive contamination along the shoreline in West Cumbria had increased at 12 of 16 sample locations. The calculations show an average of measurements taken throughout the year. The figures from EA also show a tendency towards higher concentrations in the fall than in the spring. The figures from 2001 (Newbiggin) show alpha concentrations of 3.016 Bq/kg in the third quarter. Similarly the figures from 2000 show concentrations of alpha-emitting radionuclides at 3.469 Bq/kg in the fourth quarter. The numbers from 1999 also confirm this tendency. EA maintains that this increase in alpha-emitting radioactive contamination is probably due to the motion of old contaminated sediments lying on the sea floor outside Sellafield. The transport of these sediments plays an important role in the matter of contamination of the entire Irish Sea. At times these sediments wash ashore, as for example during the spring flood or in situations of drought whereby the plutonium and other radioactive decomposition products can be spread with the wind or be taken up in the food chain through grass and plants. Even with comprehensive research on the subject, it is still difficult to ascertain how these sediments are transported around the Irish Sea. However, the information from Table 9 suggests that in certain locations the sediments have a tendency to be transported ashore, thereby creating a problem of increased radioactive contamination in the district of Cumbria.

A closer examination of the individual samples from Newbiggin shows that the radionuclides having the highest values are primarily the highly radiotoxic isotopes plutonium-239/240 and americium.241. Plutonium-239/240 and americium-241 are three of the most injurious radionuclides in existence, and inhalation of even the minutest amounts of alpha-emitting plutonium can cause cancer. The numerical data show values for plutonium of more than 850 Bq/kg in the fourth quarter of 2000. This is also confirmed by BNFL, which in 2000 reported plutonium concentrations in sludge of 820 Bq/kg in the same area (Ravenglass, five kilometres south of Sellafield).

Table 10
Total amounts of beta-emitting radionuclides in sediments in West Cumbria (Newbiggin). Average values. (Source: Environment Agency, 1999, 2000, 2001).



96 Sunday Herald, 29.06.2003.
97 Rudjord, A.L., *et al.*, 2001, page 22..

All fish caught in the Irish Sea contain traces of radioactive contamination from Sellafield.

The British Food Standards Agency (FSA) has made its own analyses as to the extent that sea-to-land transport of radioactive contamination in the Ravenglass area affects the food chain. The agency concluded that sea-to-land transports of this kind of contamination have not thus far had any outcome on the food chain.[98] However, it is difficult to make any projections about the impact on the food chain in the coming centuries of the radioactive decomposition products that are now washing ashore on the beaches.

The Environment Agency has estimated that the average values of plutonium in the sediments along the beaches in West Cumbria are around 500 Bq/kg, while the averages for caesium-137 and americium are 346 Bq/kg and 704 Bq/kg respectively.[99]

As may be seen from Table 10, beta contamination along the shoreline of Cumbria increased in the middle of the 1990s. However, it may be assumed that this was caused for the most part by the substantial discharges of beta-emitting technetium-99 (Tc-99). Because the ocean currents so readily transport Tc-99, it may also be seen that the radioactive concentrations in the environment have varied in relation to increased and reduced discharges of Tc-99 in the last few years.

None of the reports that Bellona has examined give any information about the concentrations of plutonium and other alpha-emitting radionuclides on the sea floor outside the Sellafield reprocessing plant itself. Such information is needed in order to be able to document the sources of future contamination. Nor has anyone attempted to establish how great a degree the sediments on the ocean floor outside Sellafield are contaminated. OSPAR maintains that the Irish Sea might be contaminated with more than 200 kilograms of plutonium.[100] Earlier studies have also shown that plutonium and americium accumulate in the sediments on the sea floor. British environmental authorities have estimated that the 30 kilometre long coastal area outside Sellafield is contaminated with at least 240 TBq of Pu-239/240 and 290 TBq of americium-241.[101]

6.4 Contamination of marine plants and animals

General study of how radioactive contamination is taken up into the food chain constitutes part of the British Food Standard Agency's national monitoring program. Consequently there is no monitoring program for the area specifically around Sellafield. This is somewhat

98 FSA/SEPA, 2002: Radioactivity in Food and the Environment, 2001, page 53.
99 EA, 2001: Radioactivity in the Environment. Report for 2001, page 46.
100 OSPAR, 2000, para. 4.9.3.
101 Kershaw, P.J., *et al.*, 1992.

Table 11: Radioactive contamination in fish (selected radionuclides) Bq/kg wet weight. Sellafield coastal area (BNFL: 2001)

Fish	Plutonium (alpha)	Am-241	Tc-99	Cs-137	Sr-90	Total beta (FSA 2002)
Plaice	0.03	0.05	5.1	5.6	<0.14	140
Cod	0.02	<0.02	3.8	7.7	<0.15	170
Flounder	0.03	0.03	2.1	21	<0.12	
Mackerel	0.04	0.05	7.3	2.9	<0.12	

Table 12: Radioactive contamination in molluscs and crustaceans (selected radionuclides) Bq/kg wet weight. (BNFL 2001). *All samples collected in St Bees, four kilometres north of Sellafield, except for limpet, which was collected offshore.

Molluscs/ Crustaceans	Plutonium (alpha)	Am-241	Tc-99	Cs-137	Sr-90	Pu-241 (FSA 2002)
Mussels	9	17	1 100	3	1.8	68
Limpets	12	22	2 200	9.6	5.7	66
Scallops	1.5	0.8	23	1.3	<0.24	
Crab	0.58	1.8	79	0.4	1.5	4.3
Lobster	0.35	6.1	3 700	2.9	0.42	4.3
Periwinkle	16	27	850	10	3.4	100

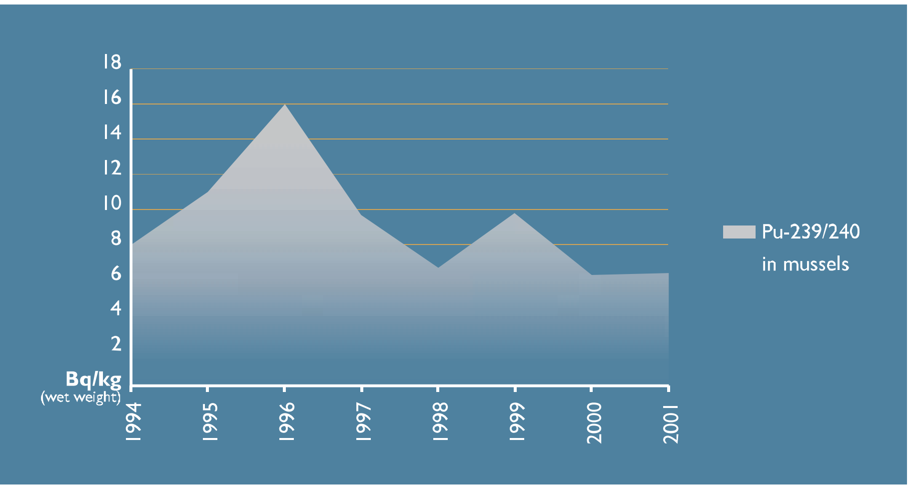


Table 13: Values of Pu-239 and Pu-240 in mussels found outside Sellafield (Source: MAFF/FSA).

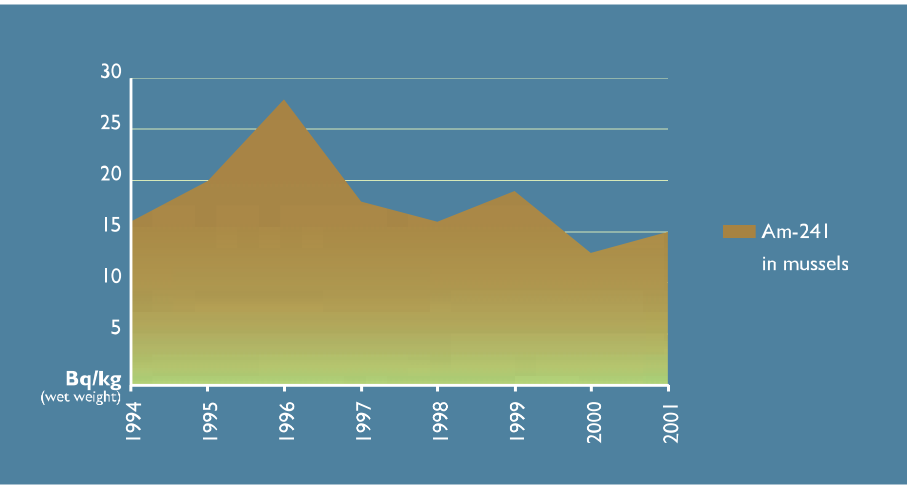


Table 14: Values of Am-241 in mussels found outside Sellafield (Source: MAFF/FSA).

unfortunate in that very few samples are taken of individual plant and animal species, and the samples that are taken are not analysed for all the pertinent isotopes. For example, in 2001, only one or two samples were taken of the different species of fish in the coastal area off Sellafield. None of the fish species were analysed for strontium-90.

Samples of bladder wrack algae were only taken at two locations within the vicinity of the plant, and only four samples were taken of mussels. Some fish species were not analysed at all, including flounder and mackerel, which are also found on the coastal area outside the Sellafield plant. Flounder and mackerel are especially significant because flounder and mackerel are used for human consumption.

In many cases therefore, the only available data comes from the operator of the facility, BNFL. Yet BNFL's own monitoring programme is limited to the most immediate areas around the facility, along with an area on the East Coast of the Isle of Man. As with the data from FSA, the BNFL material represents an average of several findings; however, unlike FSA, BNFL does not state how many samples it has taken of each individual biotope. This means that there may have been individual samples with much higher values than that which is presented in the reports.

A weakness in the figures from both FSA and BNFL is that all of the samples are presented in wet weight form. Samples in dry weight would give higher values. Certain ocean products such as seaweed for example, are utilised or consumed in dry form; alternatively, as in certain areas around Sellafield, they are used as fertiliser. Hence measurements made in dry weight would be more illuminating.

Discharged plutonium readily builds up in mussels.

The samples from the Sellafield coastal area were taken from a coastline stretching 15 kilometres north and south of the Sellafield facility and 11 kilometres out to sea. This applied to the samples taken by both BNFL and FSA

In Table 11 it may be observed that flounder takes up more of the historic Cs-137 waste which over the course of time has become mixed in with the sediments along the coast. The reason for this is that flounder for the most part tends to stay down at the ocean floor. In addition it would appear that mackerel has a greater proclivity to take up Tc-99 than other species of fish. The sample of cod was taken at Whitehaven.

Figures from FSA show fairly high concentrations of Tc-99 in plaice and sole caught offshore from Sellafield, with Tc-99 values of 64 and 67 Bq/kg respectively.[102]

The high concentrations of Tc-99 confirm that this nuclide readily builds up in molluscs and shellfish, particularly in lobster. (Table 12).

Even though BNFL has reported lower discharges of plutonium and americium since the opening of the purification plant EARP in 1994, the concentrations of these radioactive substances in the marine environment remain more or less constant. At the end of the 1990s, the concentration of Am-241, Pu-239 and Pu-240 in mussels found outside Sellafield increased, as shown by studies carried out by FSA's forerunner, the Ministry of Agriculture Fisheries and Food (MAFF). New figures from FSA confirm that the values for these elements do not appear to be sinking. (Table 13).

Table 15 shows similar tendencies. Even though the discharges of radiotoxic plutonium have been reduced, the concentrations in the environment remain stable.

Increasing values for plutonium in molluscs such as mussels have also been observed in Ireland. Studies carried out by the Radiological Protection Institute of Ireland (RPII) show that the concentration of plutonium and americium in Irish mussels at Carlingford doubled in the period between 1992 to 1998.[103] Concentrations of plutonium-239/-240 in Irish mussels today lie between 0.015 and 0.016 Bq/kg.[104] Plutonium-239 and americium-241 have

102 FSA/SEPA 2002: Radioactivity in Food and the Environment, 2001.

103 Greenpeace International, 1998.
104 Ryan, T.P. *et al.*, 2003, page 15.

a half-life of 24,100 years and 432 years respectively. Concentrations of these radionuclides in Irish seafood can vary radically from year to year as a consequence of remobilization of contaminated sediments on the floor of the Irish Sea. RPII points especially to the remobilization of contaminated ocean floor sediments as the most important cause of radioactive contamination along the coast of the Irish Sea. Caesium-137 is the dominating radionuclide, which according to RPII is responsible for 60-70 percent of the total dose of radiation to persons who make their living through harvesting seafood from the Irish Sea.[105]

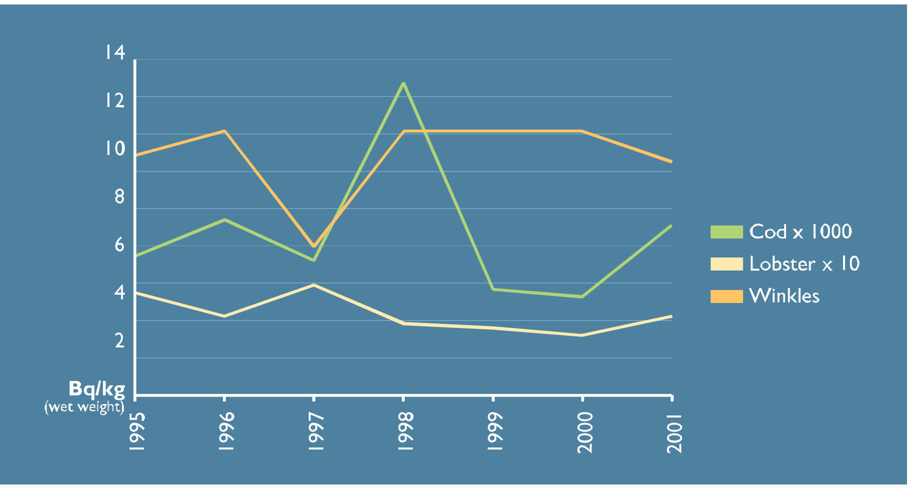


Table 15
Concentrations of Pu-239/-240 in cod, lobster and winkles (FSA/SEPA 1996-2002).

6.4.1 Contamination of seaweed

BNFL and FSA also take samples of bladder wrack outside Sellafield. Tc-99 in particular tends to build up to a considerable degree in this type of seaweed. There are no available figures for other species of seaweed and kelp, such as serrated wrack, sea girdle, and egg wrack. However, samples continue to be taken of the edible species of Porphyra umbilicalis, which used to be harvested along local beaches to make laverbread, but can also be used as a spice.

A certain weakness in the numerical data is the representation of seaweed in wet weight. In that seaweed and products made from it are usually utilised in dry weight, numerical data in wet weight gives a somewhat incorrect presentation. However, bladder wrack seaweed has a water content of approximately 72 percent; hence it is reasonable to assume that the dry weight figures can be calculated by multiplying the sample results by 3,6.[106]

6.5 Other samples from the Sellafield vicinity

Concentrations of plutonium and americium with higher values than those in the forbidden zone around Chernobyl have been found on several occasions in the area around Sellafield. In a study of radioactive contamination in Wales carried out by Her Majesty's Inspectorate of Pollution it comes to light that plutonium and americium-241 contamination of the area near Sellafield has been found in concentrations of 17 000 Bq/m^2 and 15 300 Bq/m^2 respectively. These levels of contamination are almost 100 times higher than the values that were measured in samples taken 50 kilometres north of Chernobyl (188 Bq/m^2) after the accident in 1986.[108] Her Majesty's Inspectorate of Pollution is now a part of the Environment Agency.

Greenpeace International has made similar measurements. Soil samples that the organisation took in 1998 seven kilometres south of Sellafield were analysed by the University of Bremen and showed concentrations of americium-241 of 30 000 Bq/kg. For purposes of comparison, samples taken 800 metres from the Chernobyl reactor showed concentrations of about 1300 Bq/kg. The Sellafield sample also showed concentrations of cobalt-60 of 40 Bq/kg, while the figures for caesium-137 were 9 400 Bq/kg. On the other hand, samples taken 13 kilometres from the Chernobyl reactor showed concentrations of 10 Bq/kg for cobalt-60 and 7 300 Bq/kg for every kilogram of soil.[109] The soil samples taken by the Environment Agency a few kilometres south of Sellafield at Carlton March showed concentrations of cobalt-60 at 83 Bq/kg.[110] Cobalt-60 gives off powerful gamma radiation. However, the overall total radioactive contamination is of course much higher in the Chernobyl area than at Sellafield.

Seaweed and kelp	Plutonium (alpha)	Am-241	Tc-99	Cs-137	Sr-90
Bladder wrack / fucus vesiculosus (dry weight)	30 (108)	8 (29)	25 000 (90 000)	6.9 (25)	<9 (32)
Porphyra umbilicalis	7.3	12	96	4.5	<7

Table 16: Radioactive contamination in seaweed and kelp (selected radionuclides) Bq/kg (calculated dry weight in parentheses). *Samples of bladder wrack collected at Drigg, three kilometres south of the Sellafield facility. Samples of porphyra umbilicalis collected at St Bees, four kilometres north of Sellafield. Figures from 2000.[107]

105 Ryan, T.P. *et al.*, 2003, page 15.

106 Amundsen, I., 2003, (By request): Water content in bladder wrack from Hillesøy measured by Norwegian Radiation Protection Authority.
107 BNFL, 2001: Annual Report on Discharges in the UK, 2000, page 34.
108 Greenpeace International, 1990: Coastal Pollution in the Irish Sea.
109 Greenpeace International, press release, 09.10.1998.
110 Environment Agency, 2003: Radioactivity in the Environment. Report for 2001.

These children are playing on a contaminated beach outside the village of Seascale. Sellafield may be seen in the background.

6.6 Incidences of leukaemia among the local population

Many studies show that the risk of developing leukaemia and cancer of the lymph nodes is greater for the population group growing up in and around the vicinity of Sellafield than anywhere else in Britain. In 1990, a research team from the University of Southampton led by epidemiology professor Martin J. Gardner published a five year study in which it was discovered that the incidence of leukaemia in Seascale, a small village two kilometres south of Sellafield, was ten times greater than the statistical indicators would suggest.[111] The study was published in the British Medical Journal, and found five cases of leukaemia where there normally should have been only 0.5. The same study found further that 4.5 times the number of children died of cancer in West Cumbria in the period between 1968 and 1978 than in the entire rest of the country - despite the fact that several incidences of cancer were not included in the study.[112]

A British television team had made a similar discovery on a much earlier occasion. In 1983, a documentary team from Yorkshire Television published their discovery that the incidence of leukaemia among children and youth in Seascale was seven times greater than the normal rate. All of the children who had developed leukaemia had been born and grown up in Seascale; none of them had moved to the village from other places.[113] Several other thorough studies have shown similar connections.[114]

The 1990 study concluded that children of Sellafield workers had a greater risk of developing leukaemia and cancer of the lymph nodes than other children. The study pointed out that ionising radiation at the Sellafield facility is the most likely cause of this, and suggested that exposure to this radiation could lead to a situation whereby there was a greater probability of fathers siring children who would develop leukaemia (the Gardner hypothesis).

A team of researchers from the University of Newcastle has recently substantiated the Garner theory. The Newcastle study estimates that there is a double probability that the children of fathers who have worked at the controversial facility will develop leukaemia and cancer

111 Gardner, M.J., *et al.*, 1987.
112 Downs, S., 1990.

113 Gardner, M.J., *et al.*, 1987.
114 Beral, V., *et al.*, 1993.

of the lymph nodes. The study compares the medical journals of 9 859 children of fathers who have worked at Sellafield with the medical journals of 256 851 other children in the Cumbria district in the period from 1950 to 1991. The study also showed that children under the age of seven who were born at Seascale between 1950 and 1991 had a 15 times greater probability than other children of developing lymph cancer or leukaemia. The study emphasised that employees at the facility were exposed to much higher radiation doses thirty years ago than is the rule today.[115]

Despite these statistical connections, researchers are still unable to give any conclusive evidence for the possible cause and effect relationship between Sellafield and increased risks for developing certain types of cancer. Hence more and more researchers are arguing that it is the scientific models upon which the studies are based that are insufficient to prove the connection.

BNFL on the other hand, puts greater weight on other causal relationships and supports a theory developed by Professor Leo Kinlen. Kinlen contends that the mixing of the population, which occurred when people started moving into the area to work at the facility, resulted in the spreading of a virus that could cause leukaemia.[116] The theory was first developed in 1988 by Kinlen, but has achieved very little international recognition. Nor is there any evidence of the type of virus Kinlen refers to.

115 Dickinson, H.O., and Parker, L., 2002.
116 Doll, R., 1999.

Chapter 7 Discharges of technetium-99

Discharges of technetium-99

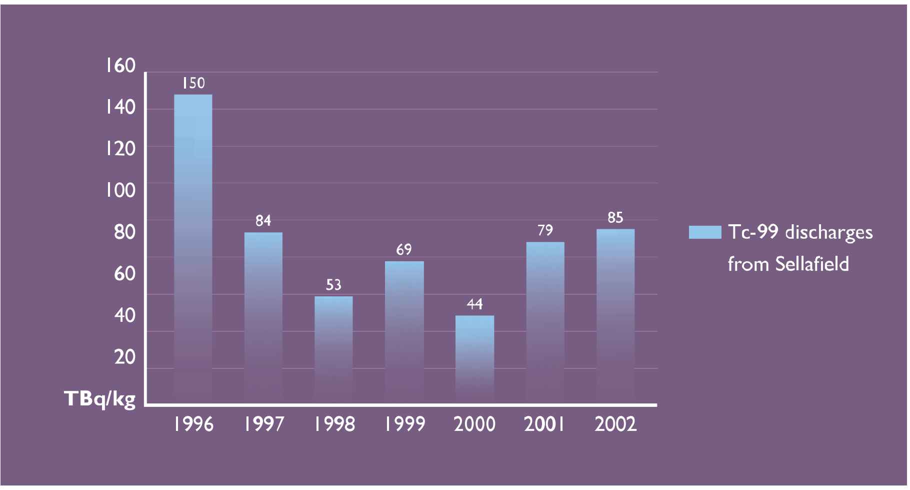


Table 17: Discharges of Tc-99 from Sellafield to the sea in the last seven years (TBq).

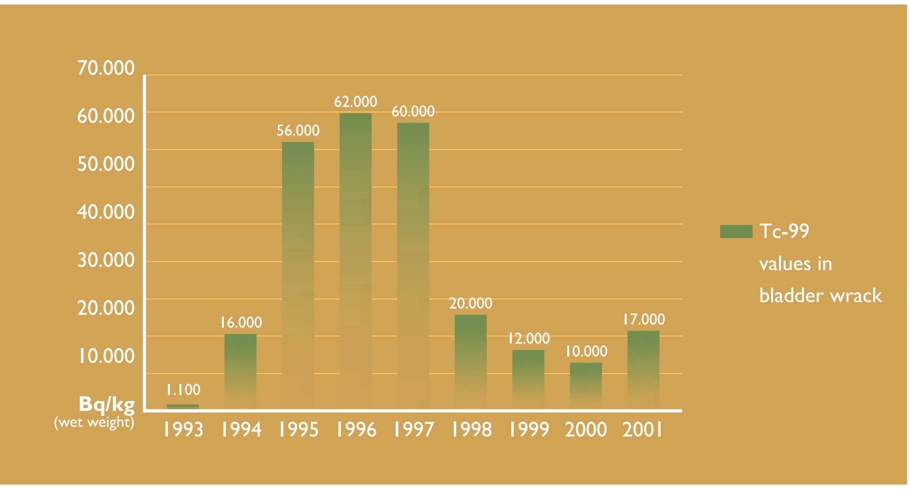


Table 18: Tc-99 values in bladder wrack (Fucus vesiculosus) outside Sellafield (Source: FSA/SEPA).
*Samples of bladder wrack represent an annual average of four samples collected outside Sellafield.

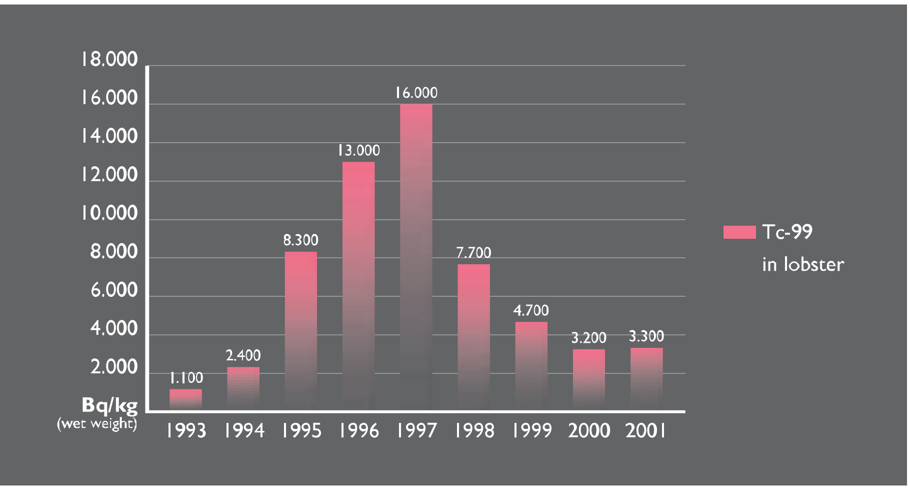


Table 19: Tc-99 values in lobster outside Sellafield (Source: FSA/SEPA).
*Samples of lobster represent an annual average of eight samples taken outside Sellafield.

In 1994, BNFL's discharges of technetium-99 (Tc-99) increased dramatically. From an average of 4-6 TBq per year throughout the entire 1980s, the discharges increased to 190 TBq in 1995. In the five-year period 1994-1998 BNFL discharged a staggering 530 TBq from Sellafield.[117] The discharges sank to some degree towards the end of the 1990s, but have risen again over the last three years (see Table 17). Tc-99 is an artificial product of fission that gives off beta radiation and has a half-life of 213,000 years. The long half-life implies in effect that the discharges are irreversible; once the substance is disposed into the environment, it remains there forever. Tc-99 is very mobile and diffuses readily with the ocean currents to other areas. This mobility and diffusion into the marine environment of Tc-99 has also led for example to the contamination of seaweed and lobsters along the Norwegian coast.

The discharges of technetium come as a result of reprocessing Magnox fuel. Early in the 1980s, liquid medium active concentrate from BNFL's Magnox reprocessing plant (B205) was stored in large tanks on the Sellafield site (building B211) starting in the early 1980s while awaiting start-up of a new purification plant (Enhanced Actinide Removal Plant (EARP)). When EARP went into operation in 1994, liquid radioactive wastes were discharged into the sea after having been cleansed at EARP. However, though EARP removes plutonium, caesium-137 and strontium-90 from the historic waste, it does not remove Tc-99. Furthermore, reprocessing activities at THORP also produce Tc-99, the difference being that discharges of Tc-99 from THORP are vitrified along with other high-level liquid waste from this plant.

In January 2000, the ceiling on Sellafield's discharge permit for Tc-99 was reduced from 200 TBq a year to 90 TBq a year. Nonetheless, the new discharge limits are still nine times higher than they were in 1993 when the ceiling was set at 10 TBq a year.[118] It would therefore appear that the discharge permit was adjusted to fit the needs of BNFL as opposed to any concern about the substance's possible impact on the marine environment. Nor has the British department for the environment set any limitations as to the total amounts of Tc-99 BNFL will be permitted to release. Consequently, BNFL is free to release as much Tc-99 as it wants to, so long as the discharges are spread out over a long period of time.

7.1 Technetium-99 in the marine environment of the Irish Sea

The enormous increase of radioactive discharges from Sellafield has had major environmental consequences in local areas surrounding the plant, and in the natural environment in the rest of the Irish Sea. Tc-99 concentrations

117 BNFL 2000: Annual Report on Discharges and Monitoring of the Environment in the UK 1999, page 28.
118 CORE Research Paper, 05.03.1998.

readily build up in shellfish and certain species of seaweed, and the substance becomes especially concentrated in lobster and bladder wrack (Fucus vesiculosus). Both BNFL and FSA take samples of bladder wrack and lobster outside Sellafield.

In Norway, seaweed is harvested and ground into a form of meal that is used as an additive in health food products. Consequently, in Norway and Ireland it is customary to present measurements of radioactivity in seaweed in terms of dry weight. In Britain on the other hand, measurements are given in wet weight, which gives the impression of lower values. Because bladder wrack has water content of about 72 percent, it is reasonable to assume that the dry weight values can be calculated by multiplying the results from the samples measured in wet weight by 3.6.[119]

Tc-99 also has a tendency to build up in egg wrack (*Ascophyllum nodusum*) and serrated wrack (*Fucus serratus*); however, neither BNFL nor FSA has taken samples of these species of seaweed outside Sellafield. FSA has taken a few samples of egg wrack in Scotland.

Table 18 and 19 show how concentrations of Tc-99 in seaweed and lobster increased rapidly after Tc-99 discharges began in 1994. EU's initiative to limit radioactivity in food (which go into effect in the event of a nuclear accident) are at 1250 Bq/kg.[120] The concentrations of Tc-99 in seaweed and lobster outside Sellafield are still well over this limit.

In the last few years, both BNFL and the Environment Agency report higher concentrations of Tc-99 in seaweed and lobster than FSA. As recently as 2000, BNFL measured Tc-99 concentrations of 25 000 Bq/kg (wet weight)[121] in bladder wrack outside Sellafield. In the same year, the company reported concentrations in lobster of 3700 Bq/kg (wet weight). The Environment Agency reported respective values in bladder wrack outside Sellafield in 2000 and 2001 at 19 900 Bq/kg (wet weight) and 8 980 Bq/kg (wet weight) - values that were double those reported by FSA.[122] The numeric data from the BNFL annual report for 1998 showed samples of bladder wrack taken at Drigg (three kilometres south of Sellafield) in which Tc-99 values were as high as 72 000 Bq/kg (wet weight). This was more than three times as high as the figures reported by FSA.[123]

However, BNFL's quarterly reports note even higher concentrations. For example, in a quarterly report from 1997, Tc-99 values of 52,000 Bq/kg (wet weight) are reported in lobster, and 140 000 Bq/kg for bladder wrack. The reference to a finding of 52 000 Bq/kg in lobster carries the remark "*subject to management investigation*".[124]

The great variation between the measurement results of the individual organisations suggests that the numerical data from FSA is conservative, and in no way shows any "worst case" cases in the local marine environment.

In Norway, the Norwegian Radiation Protection Authority has been able to demonstrate that Tc-99 values in seaweed appear to rise in the winter months.[125] This may perhaps explain the large variations in the findings that BNFL, FSA and EA have reported in the last years. Neither BNFL nor FSA state at what time of year their samples have been taken. In contrast to Norwegian seaweed, the seaweed taken from the coast off Sellafield is hardly used at all for further processing and human consumption. FSA does state however that seaweed from the coast off Sellafield is sometimes used for fertiliser on land.

Fish lack the same ability to take up the concentrations of Tc-99 as lobster and crab; however, that is not to say that concentrations of Tc-99 are not found in fish. In the port city of Barrow south of Sellafield, Tc-99 concentrations of 14 Bq were measured in plaice in 1998. Data from BNFL suggest that it is mackerel that has the greatest ability to take up Tc-99, but it was not until 2000

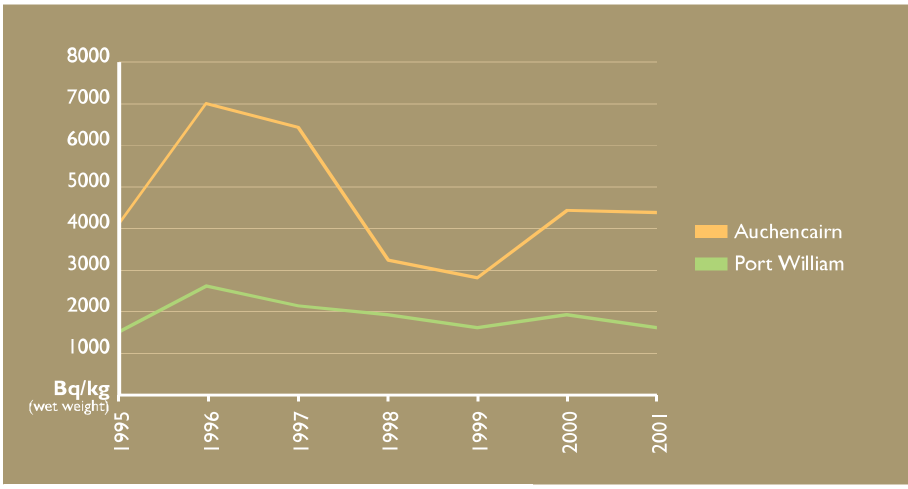


Table 20
Tc-99 concentrations in bladder wrack from Southwest Scotland (Source: FSA/SEPA).

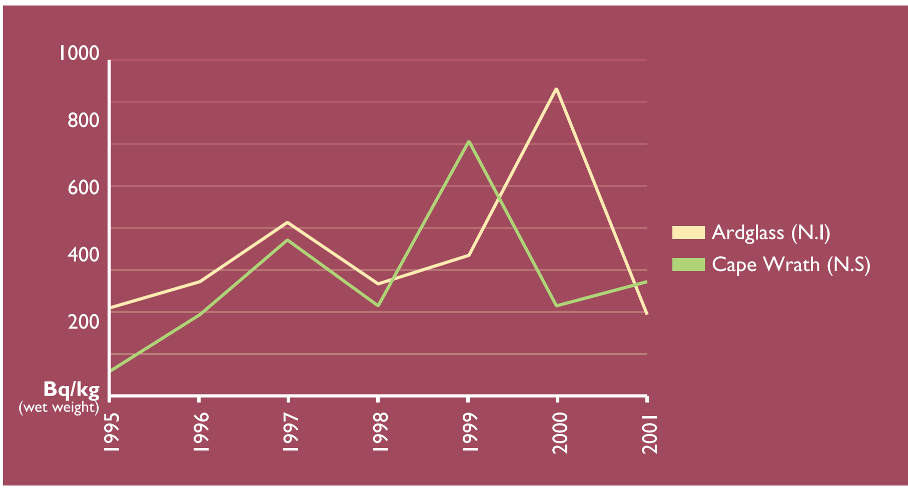


Table 21
Tc-99 concentrations in bladder wrack in North Scotland (N.S) and Northern Ireland (N.I) (Source: FSA/SEPA).

119 Amundsen, I., 2003. (By request).
120 Brown, J., *et al.*. 1998.
121 BNFL, 2001: Discharges and Monitoring of the Environment in the UK 2000.
122 Environment Agency, 2000: Radioactivity in the Environment, page 107.
123 BNFL, 1999: Annual Report on Discharges and Monitoring of the Environment 1998, page 41.
124 BNFL, 1997: Quarterly reports, referenced in CORE Briefing No. 4, 05.03.1998.

125 Kolstad, A.K., and Lind, B., 2002.

that BNFL first began to take samples of this fish species. The numbers from 2000 showed Tc-99 values in mackerel of 7.3 Bq/kg.[126]

Table 20 and 21 show concentrations of Tc-99 in bladder wrack from Scotland and Northern Ireland. The values in bladder wrack in Port William have increased thirty times in the period 1992 to 1996. Just in the year from 1995 to 1996, the values increased by 73 percent, from 1 500 Bq/kg to 2 600 Bq/kg. The highest values to have been found in Scotland so far are at 7 300 Bq/kg (wet weight) and were found in 1998 in bladder wrack near Dumfries.

The Radiological Protection Institute of Ireland (RPII) also takes measurements of Tc-99 in both bladder wrack and lobster. However, RPII measures bladder wrack in dry weight. When the discharges of Tc-99 began in 1994, a quadrupling of Tc-99 in bladder wrack seaweed was measured in Ireland in the first year. In Greenore, Irish authorities found bladder wrack with Tc-99 values of 4 640 Bq/kg (dry weight). In the year 2000 with Tc-99 measurements of 5 613 Bq/kg, the values for 2000 were comparable.[127]

Furthermore, studies made by both FSA and SEPA show that Tc-99 values in lobster on the north coast of Scotland tripled from 1994 to 1996, and doubled from 1995 to 1996. Lobster in Northern Ireland today has a Tc-99 content of 180 Bq/kg (wet weight). The highest values to be measured in Irish lobster in 2001 showed values of 322 Bq/kg (wet weight).[128]

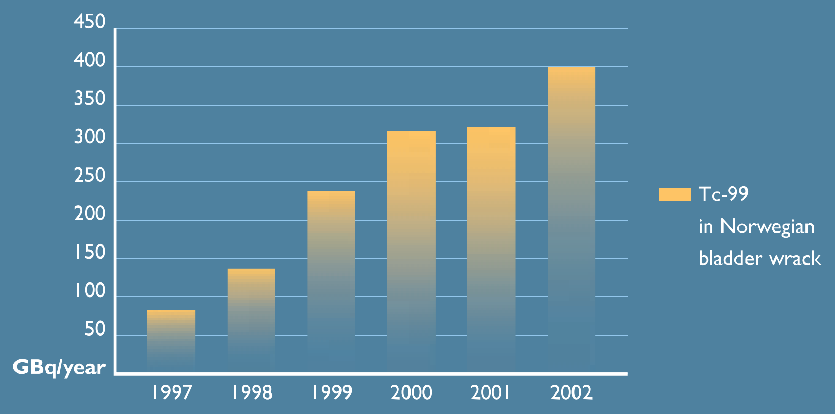


Table 22: Average annual values of Tc-99 in Norwegian bladder wrack (*Fucus vesiculosus*) at Hillesøy in Troms (dry weight). The figures are approximate (Source: Kolstad, A.K., *et al.*, 2002).

7.2 Technetium-99 in the Norwegian marine environment

Technetium-99 discharges from Sellafield take approximately 2.5 years to reach the coast of Norway. Quite soon after the heavy increase of discharges from Sellafield, heightened values of the substance were measured along the entire Norwegian coast. As early as November 1996, Tc-99 had reached the shores of Rogaland on the West Coast of Norway, and by December 1997, the substance had reached the coast of Troms in the northern part of Norway. Samples taken by the Norwegian Radiation Protection Authority in 2000 show that Tc-99 can be traced all the way to Svalbard.

Species	Locality	Bq/kg (dry weight)	Sample collection date
Bladder wrack (Fucus vesiculosus)	Lista (Rogaland)	470	05.08.00
Serrated wrack (Fucus serratus)	Lista	150	04.10.01
Sea girdle (Laminaria digitata)	Lista	26.9	04.10.01
Egg wrack (Ascophyllum nodusum)	Narestø (Aust Agder)	660	28.06.00
Egg wrack (Ascophyllum nodusum)	Narestø	435	05.10.01

Table 23: Concentrations of Tc-99 in seaweed and kelp in 2000 and 2001 (Source: Kolstad, A.K., *et al.*, 2002)

Locality	Kelp: Leaf (Bq/kg dry weight)	Kelp: Stem (Bq/kg dry weight)	Sample collection date
Kvitsøy (Rogaland)	37.7	71.5	30.08.1998
Buskøy (Sogn og Fjordane)	24.1	30.7	31.08.1998
Smøla (Møre og Romsdal)	20.5	47.4	30.09.1998

Table 24: Concentrations of Tc-99 in kelp (Laminera hyperborea). Source: Kolstad, A.K., *et al.*, 2000).

126 BNFL, 2001: Annual Report on Discharges and Monitoring of the Environment 2000, page 37.

127 Ryan, T.P., *et al.*, 2003, page 35.

128 Ryan, T.P., *et al.*, 2003, page 48.

Over the course of 1996 and 1997, Tc-99 was found in seaweed, mussels, shrimp and lobster along the entire Norwegian coast. Samples taken in the outer Oslo Fjord showed that the concentration of Tc-99 in bladder wrack had quintupled in only one year, from 36 Bq/kg in 1996 to 170 Bq/kg (dry weight) in 1997.[129] In 1998, these values again increased to 285 Bq/kg. The values measured in shrimp and mussels were much lower (varying from 2.2 Bq/kg to 7.6 Bq/kg).

7.2.1 Seaweed

Table 22 shows the average annual values of Tc-99 in bladder wrack seaweed at Hillesøy in Troms county. The concentrations vary over the course of a year, with somewhat higher concentrations in the winter months. The total picture shows concentrations to be rising. The highest values appeared in January 2002 in which measurements came out to 425 Bq/kg (dry weight). The most recent monitoring report from the Norwegian Radiation Protection Authority suggests that the concentrations of Tc-99 in Norwegian bladder wrack and egg wrack remain stable, or are increasing.

The concentration of Tc-99 in egg wrack (Ascophyllum nodusum) samples collected in 2000 at Narestø outside Arendal was measured at 660 Bq/kg.

"Stortare" (Laminaria hyperborea) is a species of kelp having a large leaf and stem up to two metres in length. Table 23 and 24 show that Tc-99 tends to build up in this kind of kelp to a lesser degree than for example in bladder wrack and egg wrack. Activity is somewhat higher in the stem than in the leaf.

7.2.2 Molluscs and shellfish

The highest concentration of Tc-99 to be measured in Norwegian lobster in 2001 was 41.5 Bq/kg wet weight (Table 25). This is approximately the same level as 1997, when the highest concentrations were measured at 42 Bq/kg in lobster in Sunnhordaland.[130] There is a big difference in the concentrations between male and female lobsters; the highest concentrations are found in female lobsters.

Bellona took six samples of lobster at Kvitsøy in October 2001. The Bellona samples showed maximum concentrations of 32.9 Bq/kg in female lobsters and 12.7 Bq/kg in male lobsters. The samples constitute a part of the numeric data in Table 25.[131]

In Table 26 it may be observed that concentrations of Tc-99 in mussels and shrimp are less than 1 Bq/kg. The levels in crawfish on the other hand are comparable with lobster. The Norwegian Radiation Protection Authority (which took the samples) does not state whether any further studies have been made of crawfish or if there is any variation between the sexes in the uptake of Tc-99 as there is in lobster. One might then assume that the concentrations of Tc-99 in Norwegian lobster are higher in some places than might be thought.

Very few studies have been made in Norway on the uptake of Tc-99 in fish. The studies from the Irish Sea indicate that there is relatively little uptake of Tc-99 in fish, with cod having less ability to take up Tc-99 than shrimp (of which there are samples). One can therefore assume that concentrations of Tc-99 in Norwegian cod are on the borderline of what can be measured. Fish that feed on marine benthos and shellfish are more likely to take up Tc-99. This also holds true for plaice and sole.

Locality	Females (variation)	Males (variation)	Number of samples
Kvitsoy (Rogaland)	34.2 (31.1 - 41.5)	6.6 (2.2 - 12.7)	4 F 17 M
Stefjord (Nordland)	20.2	2.8	1 F 1 M

Table 25: Average Tc-99 concentrations in Norwegian lobster 2001, Bq/kg wet weight. (Source: Kolstad *et al.*, 2002).

Species	Bq/kg (wet weight)	Date of sample	Collection site
Starfishes (Asteroidea)	0.16	05.10.01	Arendal
Edible crabs (Cancer pagurus)	0.18	08.08.00	Lista
Periwinkle	2.95	05.10.01	Tjøme
Sea urchin	0.22 (dry weight)	18.10.00	71 15'N, 25 26'E
Crab (Lithodes maja)	0.06	20.11.01	57 59'N, 04 26'E
Mussels (Mytilus edulis)	0.75	15.05.00	Rødtangen (Buskerud)
Crawfish	11.5	30.01.1998	Rogaland
Shrimp	0.11	30.01.1998	Rogaland

Table 26: Concentrations of Tc-99 in other seafood (Source: Kolstad *et al.*, 2000/2002).

129 Brown, J., *et al.*, 1998, page 14-15.

130 Brown, J., *et al.*, 1998.

131 Kolstad, A.K., 2002: Measurement report no. 1, 2002.

7.3
Economic values

At this time it is unclear to what degree the radioactive contamination over time of Norwegian seaweed and lobster can have a negative effect on the environment. What is certain however is that the export markets for products from the sea are very sensitive to questions of radioactive contamination. To those who are going to buy the products it matters little whether the degree of contamination is large or small - the point is that they are contaminated, and this puts consumers on their guard.

Even today the harvesting of different kinds of seaweed and kelp is big business in Norway. The export value of processed kelp products from Norway is estimated to be at least 500 million Norwegian crowns.

For the most part it is kelp (Laminaria hyperborea) that constitutes the main seaweed product harvested from the sea (about 160 000 tonnes wet weight), but about 16 000 tonnes of egg wrack is also harvested. Kelp and seaweed extracts are used to produce alginate, which in turn is used as a thickener and stabiliser in medicine, paint, ice cream, cake filers and pet foods.[132]

Bellona has been in contact with several companies that export different products made of seaweed extracts. Japanese customers have demanded reduced prices on the products from certain Norwegian companies as a consequence of the products no longer being considered to be completely clean. Studies by the Norwegian Radiation Protection Authority of Tc-99 in alginate from kelp along the coast of Norway show low values (under 1 Bq/kg dry weight.)

Lobster is also considered a possible export industry for Norway in the future. Several successful experiments have been made in putting out lobster, at Kvitsøy in Rogaland to name one. However, it is possible that radioactive contamination in Norwegian lobster could harm the development of this industry.

7.4
Future discharges of technetium-99

On the order of EA, in the summer of 2000, BNFL began to vitrify all new MAC originating from Magnox reprocessing activities in B205. Present day discharges of Tc-99 therefore come entirely from the tank facility B211. The discharge ceiling for this tank facility is set at 90 TBq a year.

There are ten tanks altogether in B211. Five of the tanks are used for storing intermediate radioactive liquid waste (medium active concentrate, or MAC); two tanks are utilised for storing the solvent from the waste; two other tanks contain liquid waste from THORP, while the last tank is an empty buffer tank.[133] The tank facility was built in 1951 and is thus over 50 years old. It is licensed through to the close of 2006, but the Health and Safety Executive (HSE) has expressed concern over the physical condition of the building. There is major rust damage in the girders, among other things.

As of June 2003, there were more than 2300 cubic metres of liquid MAC stored at B211. This waste contains approximately 230 TBq of Tc-99. Considering the great age of the tanks, BNFL has been ordered to empty them by the close of 2006. Unless the process is started of cleansing the waste of Tc-99, the discharges will continue until the end of 2006 whereupon they will be dramatically reduced when the tanks have been emptied. EA has proposed that the discharge permit for Tc-99 should be reduced to 10 TBq, but not until after 2006.

This was a strategy that in December 2002 won the support of Michael Meacher who was Minister of the Environment at the time. There was a small opening for halting Tc-99 discharges when Meacher requested the EA to assess the possibility for putting a moratorium on discharges of Tc-99 from B211. EA considered this proposal and in a letter to DEFRA dated January 7, 2002, dismissed Meacher's proposal as "non constructive".[134]

Norwegian Minister of the Environment Børge Brende has pushed hard for a halt in Tc-99 discharges and Ireland and the Nordic Council have also protested. In May 2003, Brende had a two-hour long meeting with Meacher in London in which the two ministers discussed all aspects of the matter. One of the proposals Brende took with him to London was a Bellona proposal for a 12 month moratorium on Tc-99 discharges in expectation of the development of new purification technology. This proposal eventually won through, and in June 2003, Margaret Beckett, Secretary of State for Environment, Food and Rural Affairs sent a letter to Brende in which she stated that she intended to introduce a nine month moratorium on Tc-99 discharges. The same month, the same resolution also found its way into the declaration of the ministers during the OSPAR meeting in Bremen.

In July 2003, BNFL committed itself to experiment on a large scale with tetraphenylphosphonium bromide (TPP) technology. If this new purification technology should fall into place, the discharges of Tc-99 would be reduced dramatically. The new British Minister of the Environment Elliot Morley will make the final decision on the matter.

7.5
Purification methods for technetium-99

In principle, there are three ways to purify Sellafield's liquid radioactive waste of Tc-99: build a new purification facility; expand the existing facility with new technology; or vitrify all of the Tc-99 contaminated liquid that is stored in B211.

132 Iversen, S.A. (ed.), 2001, pp. 119-121
133 Environment Agency, 07.01.2003.
134 Environment Agency, 07.01.2003.

Børge Brende, Norwegian Minister of the Environment, met his British colleague, Elliot Morley, during the OSPAR-ministrel meeting in Breme in June 2003

7.5.1 New purification facility

One way to handle Tc-99 waste is to build a new purification facility in addition to the existing EARP. The facility could utilise a form of ion exchange process (using organic sap), or a chemical process using a sodium solution that separates the Tc-99 and a filter. Uncertainty remains as to how well these techniques would work. BNFL has estimated that new purification facility of this type would cost between 100 and 150 million pounds, and that it would take about five years to build.

7.5.2 New purification technology using TPP.

Another option for handling Tc-99 discharges is to make use of a new type of purification technology. This cleansing technique entails adding the precipitation chemical tetraphenylphosphonium bromide (TPP) to the liquid waste that is being treated in EARP. The process creates a precipitant (tetraphenylphosphorium) which blends with the other precipitants that are created in the EARP process. The existing filters in EARP are then cleansed of this "TPP soup" which is then cemented and stored on land as so-called intermediate level waste. The technology is almost ready, and implementation of it will not cost more than three million pounds, including the development costs.[135]

However, the TPP process does entail being left with a few thousand extra steel barrels of Tc-99 waste stored in concrete. Since Tc-99 is a relatively mobile radionuclide, there is some doubt as to whether the concrete will be able to lastingly bind the nuclide in a long lasting future repository. The British company vested with the responsibility to plan a future nuclear repository in Great Britain, NIREX, was therefore long in doubt as to whether it could handle the new form of waste that the TPP method would create. And without approval from NIREX, BNFL could not take the technology into use. However, a paradox in this connection is that doses of radiation from potential future leaks of Tc-99 from a repository on land will be lower than the doses of radiation the most exposed population group receives today as a consequence of discharges to the sea.

NIREX carried out new studies in the spring of 2003, which showed that TPP waste is less problematic than earlier thought. The reason for this was that the earlier projections were based on outdated calculation models.[136]

One of the challenges in using TPP as a purifying agent is the adverse impact of the substance on the marine environment. Studies of TPP show that the lethal concentration of TPP for algae, invertebrates, fish larva and young fish is 1200 µg/ litre; in other words, 50 percent of the test animals died at this concentration in the seawater. Discharges of TPP to the environment must therefore be limited when using this type of purification technology. While waiting for national and international standards for TPP, the Environmental Agency has set the threshold value for TPP in seawater at 120 µg/ litre. No effect is expected at lower concentrations than this. The value is set for short-term exposure, while for long term exposure the limits are set at 12 µg/litre.[137] Therefore more testing of TPP toxicity in the environment is needed - also of ways to limit TPP discharges if it is to be utilised as a cleansing agent.

A plant trail, involving TPP was carried out during the autumn 2003.

7.5.3 Vitrification

Vitrification is a method of storing radioactive waste that entails turning the waste into glass. One possibility is to vitrify all of the liquid waste from B211. This can be done in the Sellafield WVP (Waste Vitrification Plant). Altogether, it is a matter of vitrifying approximately 2 300 of liquid medium activity waste (medium activity concentrate (MAC).

There is already a pipe between the MAC vaporising plant (B268) and WVP. Hence there should be no practical problems in transferring the waste for vitrification. Incidentally, it has also been decided that all MAC that is generated in B205 in the future should be vitrified.

One of the challenges in vitrifying all of the historic waste in B211 is that WVP is already pressed to capacity. BNFL has been enjoined to reduce the large amounts of historic Highly Active Liquor (HAL) which is being currently stored in tanks on site within the facility. In order to comply, BNFL must vitrify large amounts of HAL every year. Furthermore, if the facility is to vitrify the liquid waste in B211 as well, this could cause problems in reducing the amounts of HAL. The Health and Safety Executive (HSE) estimates the capacity of the vitrification plant to be about 475 barrels a year.

BNFL argues that the concentrations of iron and sodium in the historic MAC waste are so high so as not to be suitable for treatment in WVP. The reason for this is that the old waste has been processed in an evaporator on several occasions (to minimise the volume). BNFL has established limits for how high the concentrations of iron, salt and sodium can be in MAC prior to treatment in WVP. In the historic MAC waste today, there is 1 kg of iron and 1 kg of sodium per cubic metre of MAC.[138] One way of solving the problem would be a gradual and careful mixing of MAC in the continual stream of highly active liquor that is being treated in WVP. However, this would be a time-consuming process. Furthermore, in view of the technical physical state of B211, this would require either the construction of another building over B211, or another tank facility. BNFL estimates that a new construction over B211 would cost 100 million pounds, while a new tank facility could cost as much as 300 million pounds.[139]

135 Environment Agency, 2002: Decision Document, page 159.
136 NIREX, 20.06.2003.
137 Amundsen, I. *et al.*, 2003, page 22.
138 BNFL, 25.07.2000: Letter to Environment Agency. Referenced in Environment Agency, 2001. Explanatory document, Appendices and Annexes.
139 Environment Agency, 07.01.2003.

Chapter 8
Discharges
in the future

Discharges in the future

8.1 OSPAR

In July 1998, the British government signed an agreement that in reality commits the country to halt all radioactive discharges by 2020. The agreement was signed in Sintra in Portugal during a meeting of ministers at the OSPAR convention on preserving the marine environment in the Northeast Atlantic. All fifteen-member countries of OSPAR, as well as the European Commission signed the agreement, which states:

"*…the objective of the Commission with regard to radioactive substances, including waste, is to prevent pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances.*"[140]

In signing this agreement, the OSPAR countries, including the United Kingdom and France, acknowledged that it is unacceptable to discharge radioactive substances into the environment in the manner in which it is done today. The agreement also states:

"*The Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic level, resulting from such discharges, emissions and losses, are close to zero.*"[141]

This means that the radioactive discharges will be reduced so that the remaining concentrations of radioactivity in the marine environment are close to zero by 2020 (except for what is already there as a consequence of earlier discharges).
In essence, this means that the radioactive discharges from the reprocessing plant at Sellafield and La Hague must be immediately halted. Otherwise the concentrations of radioactivity in the environment will continue to increase, reaching levels in 2020 that are much higher than they are today. This is true because many fission products remain in the environment far longer than 20 years.
During the OSPAR meeting in Copenhagen that took place in 2000, the OSPAR countries agreed further to investigate alternatives to reprocessing, for example dry storage of spent nuclear fuel. However, Great Britain and France expressed reservation on this declaration. The most recent meeting of ministers in the OSPAR convention was held in Bremen in June 2003. Here it was established that Great Britain would effect a nine-month moratorium on discharges of Tc-99.

8.2 Alpha and beta discharges

Despite its obligations under the OSPAR convention, BNFL prognoses indicate that the company plans to increase its discharges of a number of different radioactive fission products in the coming years. This is made evident in a BNFL document sent to the UK Environment Agency in January 2000.[142] This document shows that BNFL intends to increase the total discharge of alpha activity to the sea by over 400 percent, from 170 GBq to 888 GBq, and to maintain this rate of discharge until 2009. A presentation of this may be seen in Table 28.
Discharges of plutonium will increase by more than 200 percent, from 140 GBq in 1998 to more than 400 GBq. Furthermore, the discharges of the highly radiotoxic alpha emitter americium-241 will increase by almost 280 percent compared to discharge figures for 1998. Finally, discharges of caesium-137 will increase by 140 percent, strontium-90 will increase by 200 percent and cobalt-60 will increase by 85 percent.[143]
At worst, discharges in the future will exceed the current authorised limits. BNFL writes:

Radionuclide	Worst Case (TBq)	Discharge 1999 (TBq)	Discharge authorisation (TBq)	Worst case/ authorisation
C-14	28.8	5.8	20.8	138.3%
Sr-90	47.1	31	48	98.2%
Tc-99	90.2	69	90	100.2%
Ru-106	64.8	2.7	63	102.9%
I-129	1.82	0.48	2	91%
Pu-241	46.8	2.9	27	173.3%
Am-241	0.366	0.03	0.3	122%
Pu-alpha	0.833	0.11	0.7	119%
Total alpha	1.7	0.13	1	171%
Total beta	361	110	400	90.3%
Uranium (kg)	3390	540	2040	162.2%

Table 27: Discharges to the sea. Worst case scenario, compared with discharge authorisation (Source: BNFL 2000).

140 OSPAR, 1998, page 17.
141 OSPAR, 1998, page 17.
142 BNFL, 2000: Review of Discharges, Appendix 2, page 19.
143 BNFL, 2000: Review of Discharges, Appendix 2, page 19.

"*Comparison of the total worst case discharges with the current authorised limits (...)*
shows that discharges of over half the currently authorised radionuclides are predicted to be at levels approaching or above the limits."[144]

This is confirmed by DEFRA.[145] At worst, the discharges of plutonium-241 could exceed current discharge authorisation levels by 73 percent, and americium-241 by 22 percent, while according to BNFL, the total alpha discharges could burst the parameters of the entire discharge authorisation, reaching 1710 GBq.[146] The present discharge authorisation for americium-241 is 1000 GBq. Beta discharges are also expected to be quite high, but will not exceed the discharge authorisation which is now set at 400 TBq.
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British authorities have confirmed that an increase in discharges compared to 1998 levels was planned, but that they had not planned for the increase to be so large. Yet having signed the new OSPAR agreement in which Great Britain commits itself to reducing radioactive discharges henceforth and up to 2020, the country is also committed to showing how it plans to achieve this goal. At the OSPAR meeting in Copenhagen in 2000, British authorities presented their plan, and in the document The UK Strategy for Radioactive

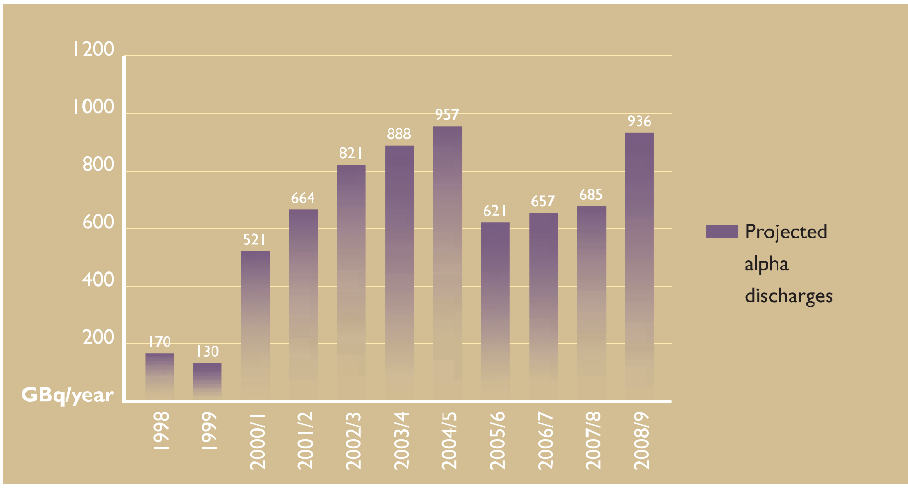


Table 28: Projected alpha discharges.[147]

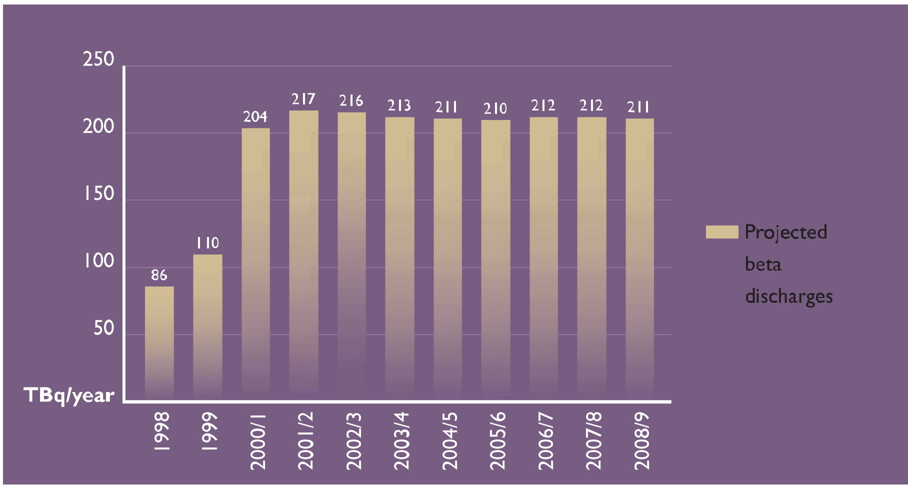


Table 29: Projected beta discharges.[148]

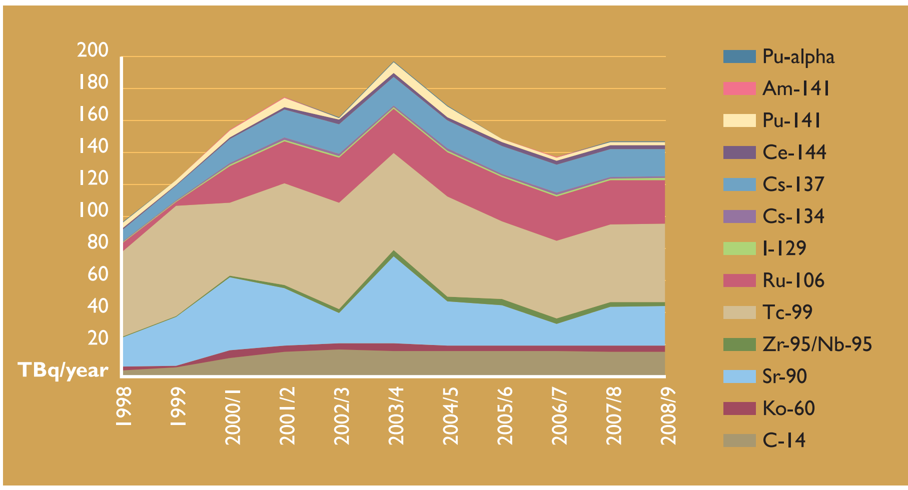


Table 30: Future discharges. Iindividual radionuclides.[149]

144 BNFL, 2000. Review of Discharges, Appendix 2, page 7.
145 The Daily Telegraph, 26.06.2001.
146 BNFL 2000: Review of Discharge, Appendix 2, table 19.
147 BNFL 2000: Review of Discharge, Appendix 1, table 16.
148 BNFL 2000: Review of Discharge, Appendix 1, table 16.
149 BNFL 2000: Review of Discharge, Appendix 1, table 16.

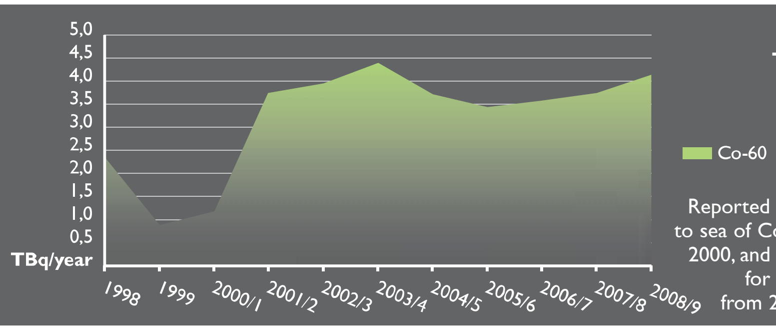


Table 31

Reported discharges to sea of Co-60 up to 2000, and prognoses for discharges from 2001-2009.

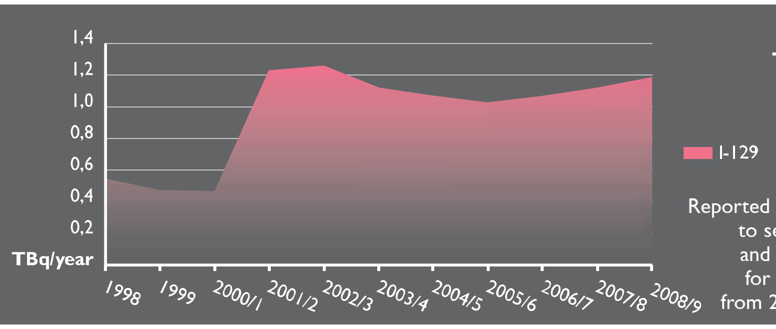


Table 32

Reported discharges to sea of I-129 and prognoses for discharges from 2001-2009.

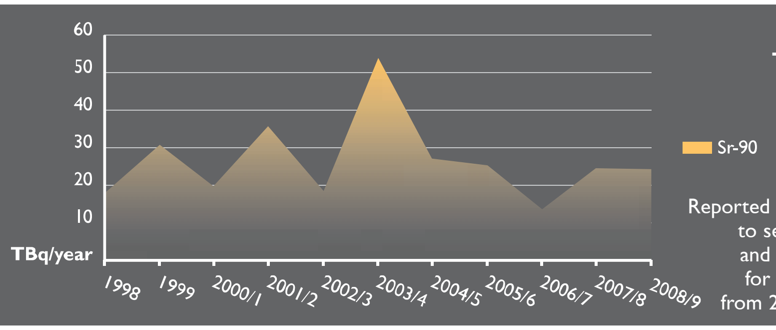


Table 33

Reported discharges to sea of Sr-90 and prognoses for discharges from 2001-2009.

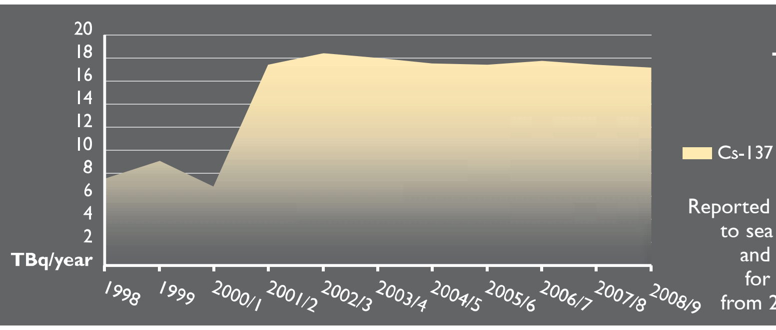


Table 34

Reported discharges to sea of Cs-137 and prognoses for discharges from 2001-2009.

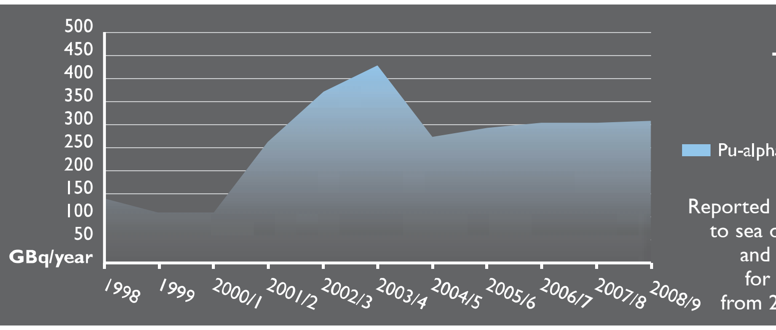


Table 35

Reported discharges to sea of Pu-alpha and prognoses for discharges from 2001-2009.

Discharges 2001-2020, the British Ministry of the Environment illustrates how the discharges are to be reduced. This document also shows a projected increase in discharges of alpha activity to about 300 GBq by 2008. However, the figures from BNFL are even higher, and the worst case figures are almost five times as high.

BNFL is also expecting beta activity discharges to increase. Compared to 1998, beta discharges will increase by almost 150 percent, from 86 TBq in 1998 to 213 TBq in the coming years. Discharges of strontium-90 alone will increase by 200 percent and BNFL plans to maintain discharges at this level until the beginning of 2009.

The dramatic increase in discharges is mainly due to two conditions. First of all, BNFL intends to reprocess all of the remaining Magnox fuel in its Magnox facilities before B205 is closed down in 2012. Secondly, THORP must reprocess large amounts of fuel in the coming years if BNFL is to fulfil the conditions of its contracts with its baseload customers. Much of this fuel has a higher burn-up than the other types of fuel that are reprocessed at THORP, and BNFL says that this could cause problems in meeting all the discharge requirements.

Tables 31 to 35 show the projected discharges from Sellafield. These projections were made in 2000. Technical problems with THORP and B205 have led to operational delays and less fuel being treated in the two plants than originally planned. This in turn has led to a situation whereby the increases in discharges have been pushed out into the future by a few years.

Chapter 9
Radioactive waste

Radioactive waste

The reprocessing of spent nuclear fuel generates new forms of radioactive waste. The volume of radioactive waste that comes of reprocessing is multiplied several times compared to direct storage of spent nuclear fuel on land. This is because all of the equipment utilised in reprocessing, such as solutions, acids, containers, filters and machine parts all become contaminated by radioactivity. The total amount of radioactivity remains approximately the same as before the fuel is reprocessed, but when the radioactive fission products are released from the fuel, they become mixed into new chemical and physical forms that in many instances are more difficult and more expensive to treat. In addition, large amounts of plutonium are produced which requires safe and secure storage.

9.1 Highly Active Liquor

Reprocessing at THORP and B205 produces large amounts of highly radioactive liquid that contains several fission products. When measured in radioactivity, this liquid (Highly Active Liquor, or HAL) represents over 95 percent of the total radioactivity that was present in the fuel before it was treated.

After the plutonium and the uranium have been extracted from the liquid, the remaining waste is transferred to separate special tanks (Highly Active Storage Tanks) to be stored. The liquid is later converted into solid form at Sellafield's vitrification plant.

More than 1 570 m^3 of high-level liquid waste is stored in tanks at the Sellafield site today.

9.2 Tank facility (B215)

The highly active liquid waste (HAL) is stored in 21 tanks (Highly Active Storage Tanks or HAST) in building B215. The waste comes from the reprocessing facilities B205 and THORP. Before it is stored in tanks, the waste is minimised in volume through treatment in three evaporators.

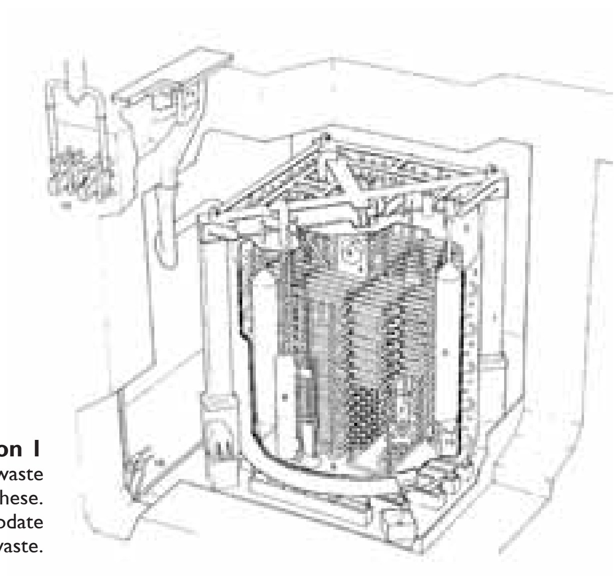


Illustration 1
Highly active liquid nuclear waste is stored in tanks such as these. Each tank can accommodate 150 m^3 of waste.

The oldest tanks in B215 were taken into use in 1955 and are now almost fifty years. Bellona has inspected the facility on two occasions. The 21 tanks can be divided into two different types of design. The first eight tanks were taken into use in the time period 1955 to 1968 and are located in their own part of the building. All of these tanks have a capacity of 70m^3. The tanks are horizontal and are constructed of stainless steel, measuring 10.6 metres in length and 3 metres in diameter. The four oldest tanks have only one cooling circuit, while the other four have three cooling circuits. The two oldest tanks contain waste from the military reprocessing facility B204. Tanks 4-6 contain waste from B205, and in these tanks amounts of radioactive sludge have settled on the bottom. Tanks 7 and 8 are empty buffer tanks.[150]

The remaining tanks (HAST 9-21) all have a capacity of 150m^3 (see illustration 1.) These tanks are cylindrically shaped 6.2 metres high and 6.2 metres in diameter. The tanks were taken into use in the period from 1970 to 1990. All of the tanks have seven cooling circuits. Tanks 10, 14, and 17 are empty buffer tanks for safety reasons. The temperature of the waste is between 50 and 60 degrees Celsius. The contents of the tanks vary from tank to tank. Active cooling is required to ensure that the tanks do not start to boil.

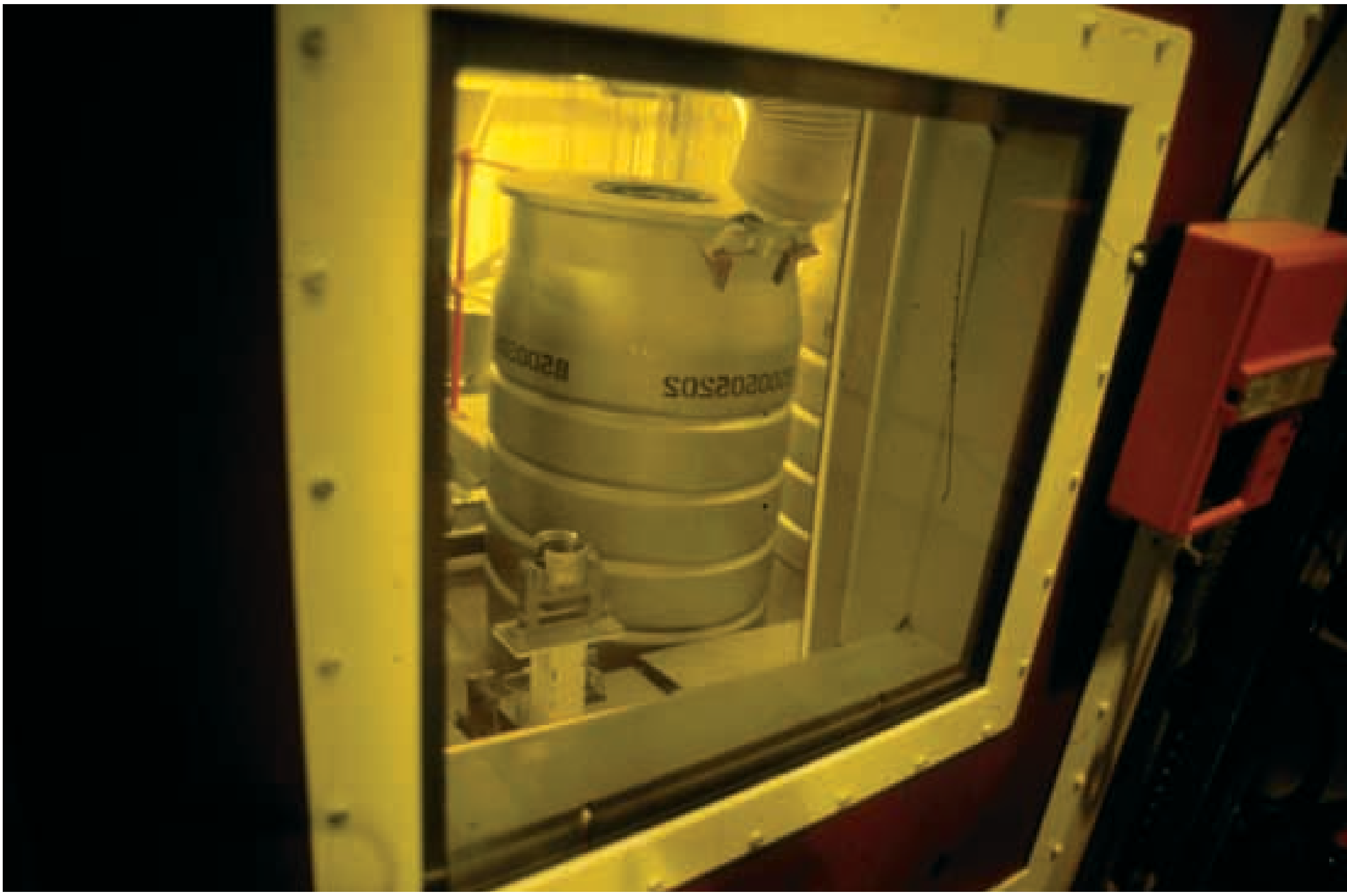
The waste in these kinds of tanks constitutes a serious safety problem. To illustrate, it was a tank like one of these that exploded in 1957 at the Soviet reprocessing facility at Mayak. The force of the explosion corresponded to 75 tonnes of TNT and was caused by failure of the cooling system at one of the tanks in the facility.[151] As a result of the accident, an area of 15 000 square kilometres was radioactively contaminated by strontium-90 and more than 10 000 people had to be evacuated from the area. Entire villages were burned to the ground and the upper layers of soil were scraped off and treated as waste. A similar accident at Sellafield would have catastrophic consequences.

95 percent of the activity in the HAL tanks is attributable to caesium-137 and strontium-90. The current amounts of caesium-137 activity in the Sellafield tanks are more than 100 times the activity that was released during the Chernobyl accident.[152]

9.3 Waste vitrification plant (WVP)

In 1990, BNFL opened a plant to vitrify (convert into glass) the large amounts of high level liquid waste generated by reprocessing activities. The plant was built

150 HM Nuclear Installations Inspectorate, 2000.
151 Nilsen, T., *et al.*, 1990.
152 Amundsen, I. *et al.*, 2003, page 2.



Highly active liquid nuclear waste is converted into glass and stored in steel containers like these.

with two production lines, which were expected to produce about 600 containers of vitrified waste per annum.[153] However, due to a series of different problems, the vitrification plant has not been operating as expected. On average, the plant has vitrified only 34 percent of the waste it is designed to handle. In 2001 the plant had produced 2 280 containers of vitrified waste.[154]

As a consequence, a third production line valued at £100 million was completed at the close of 2001. With a new production line in place, BNFL has set a goal of producing 600 barrels of vitrified waste a year. However, the Nuclear Installations Inspectorate (NII) estimates that with three production lines in operation, the vitrification plant will still only be able to produce 475 containers a year. In a letter to BNFL dated January 31, 2001, NII writes: "*BNFL's performance predictions for the Waste Vitrification Plant have historically proved over-optimistic.*" With three production lines in operation, WVP produced 320 barrels of vitrified waste in the financial year 2001/2002.[155]

9.3.1 Injunction to reduce the amount of liquid waste

The Nuclear Installations Inspectorate (NII) has ordered BNFL to reduce the volume of stored HAL to a "strategic amount" of $200m^3$ by 2015. In practice this means that BNFL must vitrify more HAL than the company manages to produce. If BNFL manages to achieve these targets largely depends upon the capacity of the vitrification facility. At present, the vitrification facility has not succeeded in producing at the rate expected, and this has delayed the process of converting the large stores of HAL into solid form.[156]

If BNFL does not succeed in raising the production capacity in WVP, it will either have to reduce the amounts of fuel to be reprocessed (so as to decrease the production of HAL), or build a fourth production line at WVP.[157] Due to the low grade of enrichment in Magnox fuel, the WVP can treat five times more liquid generated through Magnox reprocessing than it can liquid from oxide fuel, a point that BNFL confirms.[158] Hence it is the capacity of WVP that limits the amount of oxide fuel that can be

153 HM Nuclear Installations Inspectorate, 2000.
154 Forwood, M., 2001.
155 The Whitehaven News, 05.05.2003.

156 HM Nuclear Installations Inspectorate, 2000, summary.
157 HM Nuclear Installations Inspectorate, 2000, summary.
158 BNFL Engineering No. 9, 1997. Vitrification Line 3, referenced by Forwood, M., 2001.

reprocessed in THORP. Given the constraints BNFL has received from NII, it may well be difficult for the company to fulfil the commitments to its baseload contracts by the deadline of April 2005. In order to reach this goal, THORP would have to reprocess more than 1000 tonnes of oxide fuel a year, on top of the 1000 tonnes of Magnox fuel that BNFL aims to reprocess on annual basis. Given such high production, it will be impossible to reduce the stored of HAL with WVP capacity being what it is today.

9.3.2 No final repository plan

Vitrified high active waste is stored in its own building within the Sellafield compound. So far, more than 2000 m^3 of vitrified high activity waste has been produced and packed in special steel containers. The volume increases proportionally with the treatment of high active liquid waste in WVP.

Long-lived, medium active waste (intermediate level waste, or ILW) is also stored at Sellafield. This is not vitrified, but cemented into containers. The cementing of ILW began in 1990. There is a great deal of historic waste to be processed, and so far, approximately 17 000 tonnes of cemented waste have been produced.[159]

The plan is to permanently deposit both ILW and high active waste in deep geological formations at some time in the future. The Nuclear Industry Radioactive Waste Management Executive (NIREX) is a company that was established at the behest of the British nuclear industry to assess strategies for coping with all the radioactive waste, including the highly active, vitrified waste. In 1991, NIREX identified an area in the vicinity of Sellafield as a possible place to deposit the waste. NIREX proposed to build a laboratory deep under ground to carry out further studies of the location. Today the plans have been put aside, and NIREX sharply criticised for its deportment during the political discussion of the matter. Accusations were made that the location was selected on grounds of political convenience and not necessarily because of suitability of the location's physical geology. It has since come out that NIREX withheld scientific information and attempted to portray Sellafield as a more suitable locale for a repository than their studies had actually shown.[160] As a consequence of the scandal, efforts towards a final repository were set back several years. The largest producers of British nuclear waste, including BNFL Plc, UKAEA, and British Energy, are also the owners of NIREX. In July 2003 however, the British government gave signals that NIREX would be made more independent of the nuclear industry.[161]

The BNFL quay facility at Barrow

9.4 Low-level waste

Low-level waste is generated on a daily basis, both as a consequence of regular operations at the Sellafield facilities, and to an ever-increasing degree, in view of the ongoing efforts to decommission old facilities. Low-level waste in solid form is sent to the repository at Drigg located a few kilometres south of Sellafield, while low-level waste in liquid form is discharged into the sea.

Drigg is constructed in the form of an enormous concrete pool at ground level. Before any waste can be placed in the repository, it has to be converted to solid form. The repository is filled over time with steel drums, with the final plan being to fill up the "pool" again with cement and cover it over with soil. With the exception of UKAEA's repository for low-level waste in the Dounreay area, Drigg is the only repository for radioactive waste in Great Britain. Consequently, low-level waste from the whole country is transported to Drigg. In 1995, BNFL took into use a facility to compress low-level waste, the Waste Monitoring and Compaction Plant (WAMAC).[162] This facility came into use in view of the fact that Drigg will soon be filled to the rim. The drainage water from Drigg is known to contain some radioactivity, but it runs into the River Irt and flows down further to the mouth of the river at Ravenglass, a few kilometres south of Sellafield.

Much of the ground beneath Sellafield is contaminated by radioactivity and is categorised as low-level waste. However, BNFL has obtained permission to deposit this contaminated soil at an isolated site within the facility compound (The South Tip).[163]

159 NIREX, 2001: Introduction to Radioactive Waste.

160 The Guardian, 23.07.2001.
161 NIREX press statement, 16.07.2003.
162 BNFL, 2000: Annual Report on Discharges and Monitoring of the Environment 1999, page 31.
163 BNFL, 2000: Annual Report on Discharges and Monitoring of the Environment 1999, page 31.

The nuclear transport vessels Pacific Pintail and Pacific Teal in the harbour at Barrow.

9.5 Storage of plutonium at Sellafield

As of 2003, approximately 80 tonnes of plutonium were being stored at Sellafield. Of this, 55 tonnes are owned by BNFL, plutonium that has been separated over the course of many years from spent reactor fuel through reprocessing activities. Today this plutonium takes the form of plutonium dioxide and is stored as powder in stainless steel drums that are kept in their own buildings within the Sellafield compound (B302 and B302.1).

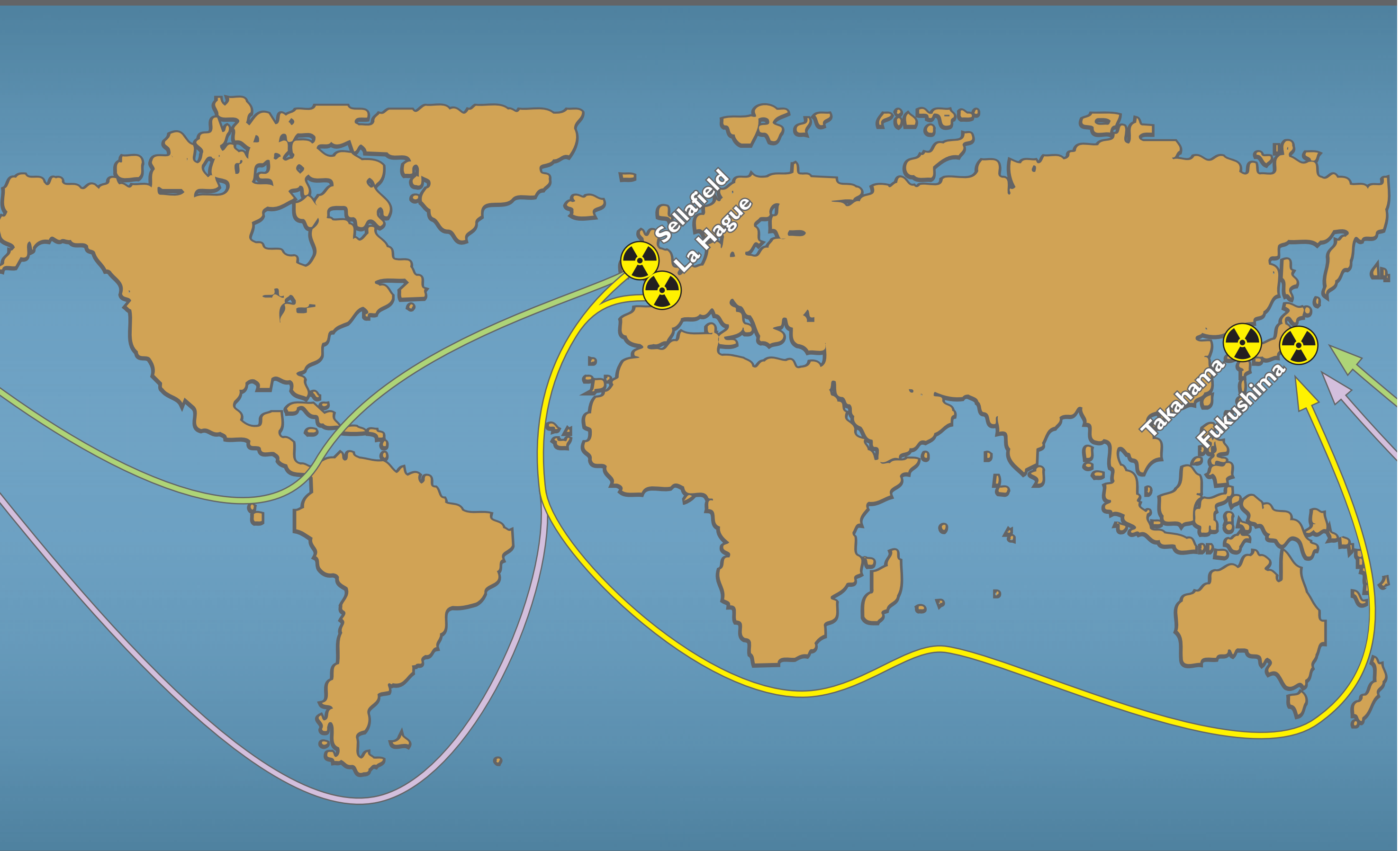
There are two risk factors connected to such large-scale storage of plutonium. First and foremost, plutonium stored in the form of plutonium dioxide is readily used in the production of nuclear weapons. In the sprit of non-proliferation, it is hence important that the plutonium does not go astray.

The second point of concern with the plutonium storage is the continual risk of a situation arising whereby the stored plutonium is somehow inadvertently released to nature and the environment. This could happen in possible acts of terror against the facility or in the event of a major fire or large explosion at Sellafield.

9.5.1 Physical safety

The buildings that contain 80 tonnes of plutonium are of relatively simple construction, build on the surface within the Sellafield complex. In other words, there are no rock barriers over the storage. A recent government report criticised the physical security around the plutonium facility. According to the report, the structure of the buildings is weak and gives poor protection against fire or explosions on the Sellafield site. The commission that made the report was appointed by the British government to assess the physical safety of the Sellafield facility following the acts of terror against the United States on September 11, 2001. The group consisted of members of MI5 and NII. Independent authorities that have examined drawings of the facility maintain that the

Different ocean transport routes for cargoes of plutonium bound for Japan.



Caribbean route South American route South African and South Pacific route

buildings are not sufficiently robust, and that they would not be able to withstand violent impact such as a plane crash, for example.[164] Today the Sellafield facility is a no-fly zone. Proposals have also been made to position cannons so as to be able to shoot down any aircraft on course for the facility. Yet despite these provisions, there is no doubt that buildings containing such large amounts of plutonium must be secured further against possible acts of terror.

9.5.2 Non-proliferation

Whatever form it takes, whether it is weapons grade plutonium or reactor plutonium, plutonium is a nuclear explosive. The United States has always held this view and demonstrated it when it detonated a nuclear bomb made of reactor plutonium in 1962. Nevertheless plutonium-239 is the preferred isotope of weapons builders. Plutonium-240 and other higher isotopes (Pu-241 and Pu-242) diminish the military value of the plutonium. In terms of security policy, there are different categories of plutonium, subject to the percentage of Pu-240. If the stored plutonium contains less than seven percent of Plutonium-240, it is considered to be weapons grade.[165]

The copious amounts of plutonium now in storage at Sellafield may be classified as reactor plutonium. Given that it takes 20 kg of reactor plutonium to make a nuclear bomb, it is hence possible to make 4000 nuclear bombs out of the plutonium that is stored there. In that the facility has produced plutonium for weapons purposes in the past, it is logical to assume that the selfsame weapons grade plutonium is also stored at the facility. With accessibility to weapons grade plutonium, 3 kg would be more than enough to make a weapon of sizeable

164 The Guardian, 20.01.2002.

165 Eriksen, V.O., 1995.

yield (1 kiloton).[166] Regardless of its classification, the plutonium storage must be properly guarded so that the substance does not go astray. Therefore thorough accounts are kept of the stored plutonium; the area where it is stored is considered to be its own security zone, and ordinary employees at the facility do not have access to this area.

In the long run, however, it is far from satisfactory that such large amounts of plutonium are stored in a form that can be so readily utilised in the manufacture of weapons. Therefore several proposals have been made as to how plutonium can be converted into a passive, more secure and less accessible form.

BNFL would like to make MOX fuel out of the stored plutonium for use in its prospective new AP-600 and AP-1000 reactors. However, it is not certain that the government will approve a new reactor program. The last nuclear power plant to be built in Great Britain, Sizewell B, was completed in 1988. It is also uncertain whether MOX fuel can be used in Britain's gas-cooled reactors. Certainly the Magnox reactors cannot use MOX. Furthermore, a security problem with using MOX would be the increased number of transports of MOX fuel in Great Britain: in that MOX fuel contains up to 10 percent plutonium, the transports could be an attractive target for terrorists. MOX fuel could also be attractive as a material in so-called "dirty bombs".

Plutonium can also be used to make other forms of mixed fuels that can be utilised in reactors around the country. One such alternative is so-called Inter Matrix Fuel.

Another possibility is to immobilise the plutonium, that is, to blend the plutonium with other liquid radioactive waste and then cast (or vitrify) it into ceramic moulds which could then be permanently stored in deep geological formations. Immobilised plutonium is virtually impossible to extract; however, this alternative necessitates the building of a facility that can carry out immobilisation on a large scale. BNFL estimates that at least five percent of the stored plutonium will have to be immobilised anyway in that it is unsuitable for use in new nuclear fuel.[167]

9.6 Transportation of nuclear waste

In 1998, BNFL started its own transportation company - Direct Rail Services (DRS). DRS is responsible for the rail transport of all fuel from the seaport town Barrow-in-Furness to Sellafield. The company is also responsible for all transports of fuel to and from the AGR plants belonging to British Energy, not to mention transports from BNFL's own Magnox plants to Sellafield.[168]

BNFL also has its own company for the sea transport of nuclear materials. This company, Pacific Nuclear Transport Ltd (PNTL), was established in 1976, with BNFL is the primary owner, and Japanese and French companies as co-owners. PNTL vessels transport spent reactor fuel from Japanese nuclear reactors to Sellafield and La Hague for reprocessing.

PNTL has seven ships in its fleet. The ships load and unload fuel at BNFL's private quay facility in Barrow in the Cumbria district. The vessels are loaded and unloaded at BNFL's private port in Barrow, Cumbria. The vessels are authorised as INFR3, which is the International Maritime Organisation's (IMO) maximum safety classification for ships.[169] Two of the vessels, Pacific Pintail and Pacific Teal, both have a 30 mm naval cannon installed on quarterdeck, and if the vessels are transporting plutonium or MOX fuel, the presence of armed personnel are also required on board. The chambers in which the fuel is stored during transport are sealed off, and there are no cranes on board the vessel. This makes it much harder to steal the transport bottles. European Shearwater is another vessel that is frequently utilised, and is engaged primarily in transporting Swiss and German fuel from Cherbourg.

Chile, Argentina, South Africa and New Zealand have all protested against BNFL's transportation of MOX, spent reactor fuel and high level nuclear waste close to their territorial waters. Due to intense public protest, Japanese companies (the Federation of Electric Power Companies) have negotiated with Russian authorities concerning use of the Northeast Passage as a future transportation artery for high level vitrified waste from La Hague and

Name of vessel	Year built	UO2-capacity (bottles)	Magnox-capacity	Dead-weight
Pacific Swan	1978	20	4	3 800
Pacific Crane	1980	24		3 800
Pacific Teal	1982	24		3 700
Pacific Sandpiper	1985	20	9	3 775
Pacific Pintail	1987	24		3 865
Mediterranean Shearwater	1982	6	6	1 600
Atlantic Osprey	1986			2 515

Table 36: BNFL's transport vessels for reactor fuel and highly active nuclear waste.

166 Ibid, page 194.
167 The Environment Council, 2003: Plutonium Working Group, final report.
168 BNFL Annual Report & Accounts 1998.
169 BNFL Annual Report & Accounts 2000

Sellafield. If this goes through, transports will follow the coast of Norway before (with the help of Russian nuclear ice breakers) finding their way through the Northeast Passage on their way to Japan.

BNFL recently bought a seventh ship to add to its fleet - MV Arneb. The ship has now been renamed Atlantic Osprey, and will be used to transport MOX fuel between Sellafield and the European mainland. The biggest difference between this ship and the other BNFL ships is that Osprey is a roll-on/roll-off (ro-ro) vessel built to transport the lorries that transport the fuel.

Several organisations have expressed their scepticism to using ro-ro vessels to transport MOX fuel. Atlantic Osprey has a lower security clearance (classified as INFR2) from IMO than the other transport vessels. The vessel has lower safety standards than Pacific Pintail and Pacific Teal, it has no reserve engine to take over in the event of the ship's engine going dead, and furthermore, it is only a single hulled vessel.

Chapter 10
Discussion

Discussion

Sellafield today is considered to be one of the most major contributors of radioactive contamination to the Arctic marine area. Contamination from the plant can be traced in the environment from the Irish Sea to the Barents Sea. Because of the discharges from Sellafield, the Irish Sea is today the world's most radioactive polluted sea area.

Still, there is little knowledge of how radioactive fission products and transuranium elements move in the environment, or how they affect people and the environment, especially the vulnerable environment of the Arctic. Several of the substances discharged from Sellafield have such very long half-lives such that once they are released into the environment, they will essentially remain there forever seen from mankind's perspective of time. Furthermore, it is impossible to reverse the damage to the environment caused by these discharges. Several studies show that the discharges from Sellafield not only remain in the marine environment, but that the substances are transported to shore via sediments, sea mist or shore sand along the entire coast of the Irish Sea. No one really knows what effect these radioactive concentrations will have on humans and the natural environment in a long-term perspective.

During a meeting between ministers at the 1988 OSPAR -convention, the United Kingdom committed to reducing the discharges from Sellafield whereby the remaining radioactive concentrations in the marine environment would approach zero by the year 2020 (not including the concentrations already present there as a consequence of earlier discharges). In reality this means that the discharges will have to be reduced immediately, in order to completely cease in the future. Otherwise, the concentrations of radioactivity in the environment will be higher in 2020 than they were when the agreement was signed in 1998. Yet as this report shows, BNFL nevertheless intends not only to continue, but also to increase its discharges from Sellafield.

The considerable discharges from Sellafield notwithstanding, the economic parameters for reprocessing have also changed dramatically since the close of the 1970s. At the time, there was increasing concern that the world's reserves of uranium would be depleted by the end of the 20th century. Hence it was considered very sensible to extract uranium from spent reactor fuel and reuse it. However, the predictions of a uranium shortage have proven to be wrong, and today the price of uranium is lower than ever.

Nor has the development of the so-called breeder reactors proceeded as expected. The breeder reactor is a particular type of reactor that runs on uranium/plutonium fuel, which was meant to produce more plutonium than it consumed - plutonium, which could thereby be used as new fuel in the reactor. While in the 1970s this reactor type was considered to be the reactor of the future, the view today is very different. The world's largest breeder reactor, the French Superphénix, was finally shut down in 1998 after a series of serious problems and leaks from the primary circuit.[170] The British breeder programme was ended in 1994, and the German breeder reactor in Kalka never even went into operation. Today, only Japan and Russia continue active research on breeder reactors.

As of July 2003, there are at least 80 tonnes of plutonium stored at the Sellafield site. Considering the further 50 tonnes in storage at the French reprocessing plant in La Hague and the multiple tonnes of weapons-grade plutonium that will come to light when the United States and Russia begin to implement the disarmament agreement START 2, there is no longer any need to "recycle" plutonium from spent reactor fuel. The large stores of different types of plutonium that exist at Sellafield are an enduring security problem as well as a potential threat to the environment. Until sound and sensible methods of managing the existing stocks of plutonium are developed, further production of the substance is simply not justifiable. Furthermore, it is impossible to eliminate all of the radioactive substances produced by reprocessing using today's technology.

Therefore, in view of health, environment and security concerns, Bellona considers continued reprocessing of spent nuclear fuel to be unjustifiable. The environment surrounding Sellafield is already so contaminated that every new discharge of radioactivity violates the OSPAR convention, the public health and environmental safety in the area. Likewise, the discharges of technetium-99 must be stopped once and for all. As long as the discharges from Sellafield are allowed to continue, the United Kingdom will stand out as the primary culprit for spreading radioactive pollution in Europe.

170 Reuters, 03.02.1998.

Appendix 1

Managing the Nuclear Legacy

In November 2001, the Government announced radical changes to current arrangements for the clean up of Britain's nuclear legacy. These arrangements will be funded by the taxpayer.

A White Paper, "Managing the Nuclear Legacy - a strategy for action", was published in July 2002. A key proposal of the White Paper is the establishment of a new public body, the Nuclear Decommissioning Authority (NDA).

The Government set out proposals for the NDA in its Energy Bill in November 2003. The NDA will be a national body, established by primary legislation, with responsibility for legacy facilities in the UK. This body will provide the strategic direction for cleaning up Britain's civil public sector nuclear sites.

The NDA is not intended to carry out clean up work itself. Instead, it will place contracts with site licensees, currently BNFL and UKAEA, who will be responsible for the clean up programme at each site. Site licensees will need to meet relevant regulatory requirements and will be incentivised through contracts to drive forward the clean up work. The NDA will provide the required overall management and direction for legacy clean up.

BNFL operates a range of plants and facilities at its Sellafield site, in particular THORP and SMP, which provide commercial fuel services to private sector and overseas customers. These, and the wastes, materials and spent fuel at Sellafield owned by BNFL's commercial customers, are not part of the legacy. Furthermore, THORP and SMP were built with decommissioning in mind.

The nuclear legacy primarily consists of:

- Nuclear sites and facilities currently operated by the United Kingdom Atomic Energy Authority (UKAEA) and British Nuclear Fuels plc (BNFL). These were developed in the 1940s, 50s and 60s to support the Government's research programmes. Also included are the wastes, materials and spent fuel produced by those programmes. The combined undisclosed liabilities of BNFL and British Energy are £7.1bn.
- Liabilities arising from the Joint European Torus (JET), which supports fusion research at UKAEA's Culham site
- The Magnox fleet of nuclear power stations currently operated on the Government's behalf by BNFL. Also included are plant and facilities at Sellafield used for the reprocessing of nuclear fuel and all associated wastes and materials.

The cost of the total legacy is currently estimated at some £48 billion in total.[171] This figure represents the best estimates based on current knowledge and the successful application of today's technology. In practice, however, there are uncertainties about what needs to be done to deal with particular installations or wastes. Initial estimates put the NDA's operating costs in the range of £25-30 million pa.

171 Dti 2003: Funding Clean Up

Appendix 2

Discharges to the Sea from Sellafield 2000

Radionuclide	Current discharge authorisation (GBq/year)	New proposed limits for discharges	Reported discharges (GBq/year)
Carbon-14	21 000	21 000	4 600
Sulphur-35			360
Magnesium-54			10
Iron-55			40
Cobalt-50	13 000	3 600	1 200
Nickel-63			430
Zinc-65			30
Strontium-89			640
Strontium-90	48 000	48 000	20 000
Zirconium-95			110
Niobium-95			90
(Zr-95 + Nb-95)	9 000	3 800	200
Technetium-99	90 000	90 000	44 000
Ruthenium-103			110
Ruthenium-106	63 000	63 000	2 700
Silver-110m			80
Antimony-125		(new limit) 25 000	7 800
Iodine-129	2 000	2 000	470
Caesium-134	6 600	1 600	230
Caesium-137	75 000	34 000	6 900
Caesium-144	8 000	4 000	550
Promethium-147			350
Europium-152			70
Europium-154			60
Europium-155			50
Neptunium-237		(new limit) 1 000	30
Plutonium-alpha	700	700	110
Plutonium-241	27 000	25 000	3 200
Americium-241	300	300	30
Curium-243 + 244		(new limit) 69	3
Uranium (kg)	2000	2 000	610
Tritium (H-3)	30 000 000	20 000 000	2 300 000
Total alpha	**1 000**	**1 000**	**120**
Total beta	**400 000**	**220 000**	**77 000**

(Source: OSPAR 2000, BNFL 2001, EA 2002).

Magnox reactors

The reactors at Calder Hall were the first of a whole new generation of British reactors that later came to be known as Magnox reactors. In total, 26 such reactors were built in the United Kingdom. Except for Calder Hall and its sister power plant, Chapelcross, all of the reactors were constructed in the period between 1960 and 1970. Of these reactors, 12 are still in operation and dispersed between five different plants. The production of electricity by Magnox is low, and the Magnox reactors in operation account for only 5.5 percent of electricity production in England and Wales.[172]

Calder Hall and Chapelcross were built and run by UKAEA, but in the early 1970s, all of the Magnox plants were transferred to a separate, government-run company called Magnox Electric Plc. In 1998, this company was integrated into BNFL which today owns and manages all of the British Magnox reactors. Spent fuel from all of the Magnox reactors is reprocessed at BNFL's Magnox reprocessing plant (B205) at Sellafield.
Today, Great Britain is the only country to operate Magnox reactors. Early in the 1960s, British Magnox reactors were delivered to Japan (one) and Italy (one), but both of these are now shut down. The Japanese Magnox plant was shut down in 1998.[173]
The name Magnox comes from the special kind of fuel used in the reactors. While most reactors in use today utilise fuel in the form of uranium oxide (UO_2), the Magnox reactors are run on a natural metallic uranium form of fuel. This is encased in a special magnesium oxide cladding, hence the name Magnox.
The use of metallic Magnox fuel has been very problematic, both from an environmental and security-related vantage point. Uranium metal corrodes very easily in contact with water and damp compared to ceramic uranium oxide. When metallic uranium comes in contact with damp, it decays into powder of uranium oxide and uranium hydride, both of these are flammable. Corroded fuel constitutes a considerable safety problem.
With the exception of the Wylfa power plant, all of the Magnox plants utilise water pools for storage of spent nuclear fuel. This was the natural and obvious way to store spent nuclear fuel in the 1960s. In contrast to dry storage, the risk of corrosion and deterioration in Magnox fuel is clearly much greater in wet storage. To diminish this risk, BNFL's goal is to reprocess the fuel as soon after its removal from the reactors as possible.
BNFL produces its own Magnox fuel at Springfields, close to Preston. The Springfields plant was established in 1960 and produces 700 tonnes of Magnox a year, although its production capacity is almost double that.[174]
In May 2000, BNFL announced that it would close down most of its Magnox reactors by the end of 2010. Production of Magnox fuel at the Springfields plant will end in the same year. Three nuclear power plants have already closed as a consequence: Hinkley Point (2000), Bradwell (2002) and Calder Hall (2003). Calder Hall was actually supposed to operate until 2006, but technical problems at the facility led to the closing down of all four Calder Hall reactors in the course of 2002/2003. BNFL has promised that the remaining Magnox plants will not operate beyond these dates. Subject to safety and market considerations, they may be shut down sooner.[175]
Originally, BNFL had planned to prolong the lifetime of certain individual Magnox nuclear power plants through the development of a new ceramic fuel called Magrox specially designed for these reactors.[176] However, technical and economic problems lead to the shelving of Magrox fuel plans in 2001.
Over the last years BNFL has had considerable trouble with its old Magnox reactors. Due to major technical problems, all four reactors at Hinkley Point and Bradwell were inoperative for almost all of 2000. As a result of the difficulties with the reactors, BNFL ultimately decided to close Hinkley Point for good. The decision became final after an economic study concluded that an investment of several million pounds would be necessary to keep the plant going. As a consequence of the problems, the already low electricity production of the Magnox plants fell a further 15 percent from 1999 to 2000.[178]
There was trouble again on July 5, 2001 when a canister containing 25 spent fuel rods fell to the floor at the Chapelcross plant in Scotland.[179] After this accident, BNFL temporarily halted all refuelling activities at Chapelcross

Name of power plant	Number of reactors	BNFL planned closure	Age at planned closure	Output
Chapelcross	4	2005	45/47	196 MW
Dungeness A	2	2006	40	450 MW
Sizewell A	2	2006	40	420 MW
Oldbury	2	2008	40	434 MW
Wylfa	2	2010	38	980 MW

Table 37: Magnox reactors still in operation.[177]

172 BNFL, 2002: Annual Report and Accounts 2001.
173 Nuclear Engineering International, 2001.
World Nuclear Industry Handbook 2001: pp. 158-159.
174 Nuclear Engineering International, 2001.
World Nuclear Industry Handbook 2001: page 243
175 BNFL 23.05.2000.
176 BNFL, 23.05.2000.
177 BNFL, 2003: EH&S Report 2001-2002, page 15.
178 BNFL, 2001: Annual Report and Accounts 2000, page 16.
179 Wise News Communiqué 552.

and Calder Hall which both use the same refuelling system.[180] The final result of the matter was that BNFL had to move forward the closing of the two old power plants to 2003 for Calder Hall and 2005 for Chapelcross respectively.

The Wylfa nuclear power plant (completed in 1971) is the third Magnox facility that BNFL has had problems with. Both reactors at this plant were closed in April 2000 when weaknesses were discovered in the concrete construction of the reactors.[181] The facility remained closed for 15 months before the production of power resumed in August 2001.

BNFL hopes to build four to six new light-water reactors in the same location that some of the shut down Magnox reactors now stands. These new reactors have been developed by the BNFL owned company Westinghouse, and have been given the names AP 600 and AP 1000.

The British government has proposed a goal to reduce the country's CO_2 emissions by 60 percent by 2020. In order to achieve this, the government would like to pursue alternative sources of energy, and the construction of new nuclear power plants has been laid on ice for the time being. However, the government is open for a new assessment of nuclear power at a later point in time.[182]

180 BNFL press release, 08.07.2001.
181 Large, J.H., 2001, page 9.
182 DEFRA, 2003: Energy White Paper.

Other reprocessing facilities

La Hague

The French reprocessing plant La Hague along with Sellafield are the main originators of radioactive contamination in the Northeast Atlantic, the North Sea and the Barents Sea. Even though discharges from La Hague are smaller than those from Sellafield, they too can nevertheless be traced all the way to the Barents Sea. The existing transuranic substances along the coast of Norway originate from discharges from both Sellafield and La Hague.

There are two large reprocessing plants at La Hague: UP2, which went into operation in 1966; and UP3, which went into operation in 1990. Discharges flow through effluent pipe 1 700 metres from the shore. Since 1966, the plant has reprocessed more than 16 000 tonnes of fuel.

Generally speaking, discharges from La Hague tend to be considerably lower than discharges from Sellafield, with the exception of tritium (H-3) and Iodine-129, which are much higher from La Hague than from Sellafield. The discharges of Tc-99 from La Hague are less than 1 TBq, and alpha discharges in the year 2000 lay around 37 GBq.[183] This is a third of the alpha discharges from Sellafield, which were 120 GBq. However, La Hague too plans to reprocess fuel with a higher burn-up, whereby the discharges from the French plant may also increase in the coming years. In addition to this, there are also plans for reprocessing MOX fuel at La Hague. Despite lower actual discharges, the ceilings of the French discharge authorisations are in fact higher than the British. This gives La Hague more leeway to increase its discharges if it should be considered necessary. For instance, the current La Hague discharge authorisation for alpha activity to the sea is 1 700 GBq as opposed to 1 000 GBq for BNFL. Discharges of Iodine-129 from La Hague are very high, and in 2000 were at 1 400 GBq as compared to 470 GBq from Sellafield.[184] Iodine-129 has a half-life of 17 million years, and is very mobile within the environment. The long half-life combined with the fact that the substance diffuses relatively easily implies that the substance could accumulate in the food chain.

Dounreay

Dounreay in Scotland used to be the centre of reactor research in the United Kingdom. There used to be two reprocessing plants and two fast breeder reactors at Dounreay. The largest of the two reprocessing facilities could process 8 tonnes of spent nuclear fuel a year, and was opened in 1980.

The concept behind so-called fast breeder reactor was that by using nuclear fuel produced by for example plutonium, more fuel would be produced (plutonium-239) than was spent (uranium-235). Yet despite nearly 40 years of fast breeder research, the reactors have never really worked as expected, and Britain's costly fast breeder programme was finally ended in April 1994. The reprocessing plant at Dounreay was finally shut down in 1996, after some serious problems with the technical system.

Nevertheless, there are still 25 tonnes of spent nuclear fuel being stored at Dounreay. As late as July 2001, the British government decided against reprocessing this fuel at Dounreay, with the consequence that Dounreay was shut down for good. This left La Hague and Sellafield as the only commercial reprocessing plants left in Europe.

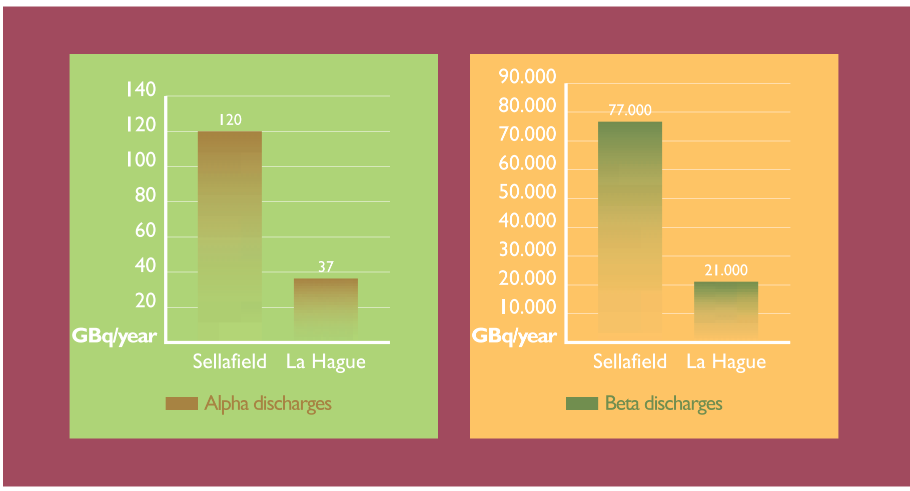
Whether the fuel stored in Dounreay will be sent to Sellafield for reprocessing or continue to be stored in Dounreay, has yet to be decided.[185]

The shut down reprocessing facility at Dounreay in Scotland.

Mayak

The Russian reprocessing plant Mayak is thoroughly discussed in Bellona Working Paper No. 4: 1995: "Reprocessing Plants in Siberia", and consequently does not receive any attention here.

Table 38:
Comparison of alpha and beta discharges from Sellafield and La Hague in 2000 (GBq/year). (Source: OSPAR, 2002).



183 COGEMA, 2001: Yearly Assessment 2000 of COGEMA - La Hague plant releases.
184 OSPAR, 2002: Liquid Discharges from Nuclear Installations in 2000.
185 Bellona Web 26.07-2001.

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