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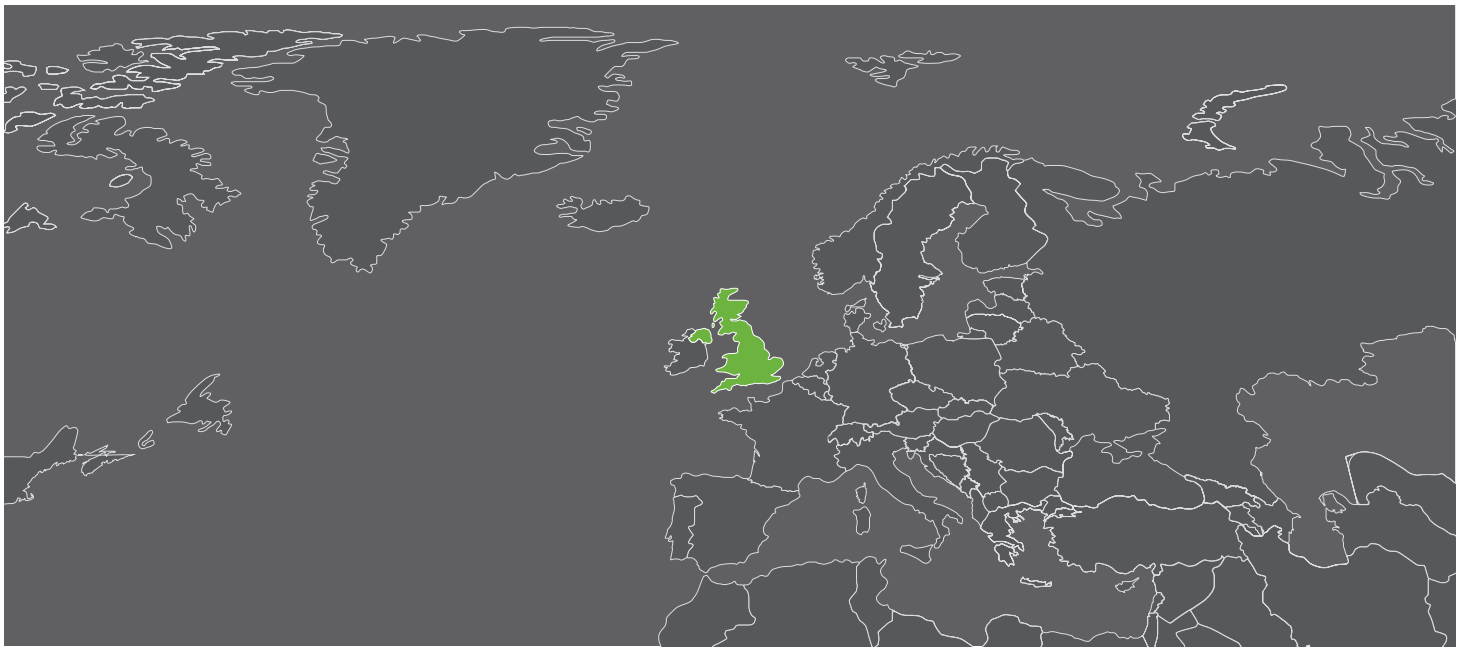

IPFM
INTERNATIONAL PANEL
ON FISSILE MATERIALS

Endless Trouble

Britain's Thermal Oxide Reprocessing Plant (THORP)

Martin Forwood, Gordon MacKerron and William Walker

Research Report No. 19
International Panel on Fissile Materials

Endless Trouble: Britain's Thermal Oxide Reprocessing Plant (THORP)

On the cover: the world map shows in highlight the United Kingdom, site of THORP

Dedication

For Martin Forwood (1940–2019)
Distinguished colleague and dear friend

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About the IPFM

The International Panel on Fissile Materials (IPFM) was founded in January 2006 and is an independent group of arms control and nonproliferation experts from both nuclear-weapon and non-nuclear-weapon states.

The mission of the IPFM is to analyze the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. These fissile materials are the key ingredients in nuclear weapons, and their control is critical to achieving nuclear disarmament, to halting the proliferation of nuclear weapons, and to ensuring that terrorists do not acquire nuclear weapons.

Both military and civilian stocks of fissile materials have to be addressed. The nuclear-weapon states still have enough fissile materials in their weapon stockpiles for tens of thousands of nuclear weapons. On the civilian side, enough plutonium has been separated to make a similarly large number of weapons. Highly enriched uranium is still used in civilian reactor fuel in many locations. This material could be used to make Hiroshima-type bombs, a design well within the potential capabilities of terrorist groups.

The Panel has been co-chaired since 2015 by Alexander Glaser and Zia Mian of Princeton University and Tatsujiro Suzuki of Nagasaki University, Japan. Previously, it was co-chaired by Jose Goldemberg of the University of Sao Paolo, Brazil (2006-2007), R. Rajaraman of Jawaharlal Nehru University, New Delhi, India (2007–2014), and Frank von Hippel of Princeton University (2006–2014).

Its members include nuclear experts from 16 countries: Brazil, Canada, China, France, Germany, India, Iran, Japan, Norway, Pakistan, Russia, South Africa, South Korea, Sweden, the United Kingdom, and the United States. This group of countries includes seven nuclear-weapon states and nine non-nuclear-weapon states.

IPFM research and reports are shared with international organizations, national governments, and nongovernmental groups. It has full panel meetings once a year in capitals around the world in addition to specialist workshops. These meetings and workshops are often in conjunction with international conferences at which IPFM panels and experts make presentations.

Princeton University's Program on Science and Global Security provides administrative and research support for the IPFM.

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Introduction

In November 2018, after 25 years of separating plutonium from domestic and foreign spent fuel from nuclear power reactors, Britain's troubled Thermal Oxide Reprocessing Plant (THORP) at Sellafield started to wind down operations and move to a clean-out program as part of the plant's final shutdown. This is a prelude to the plant's decommissioning and the treatment, disposal and management of its various remnants that may take even longer to complete.

Located on the United Kingdom's Cumbrian coast of the Irish Sea, Sellafield—initially called Windscale—was the place chosen in the late 1940s to produce plutonium for Britain's atomic bombs. Plutonium is central to Sellafield's story. Like uranium-235, plutonium-239 has been valued as both a nuclear-weapon material and source of energy in power stations. Absent in nature, plutonium-239 is a product of the irradiation of the abundant isotope uranium-238 by neutrons in a nuclear reactor. The material is separated by chemical means ("reprocessing") from residual uranium and radioactive wastes after spent fuel containing them has been discharged from a reactor. The technology is unusually difficult given the need to shield workers and the public from inescapable, dangerous, long-lasting radioactivity.

The site was chosen due to its distance from large cities, presence of cooling water and access to the sea for disposing of radioactive wastes, a practice that was initially regarded as acceptable. It was expanded to serve civil purposes when the "Magnox" design of reactor used in the military program was adopted for nuclear power stations built across the UK in the 1950s and 60s. Besides producing plutonium, it was considered necessary to reprocess Magnox spent fuels on safety grounds since their cladding corroded in water ponds used for their cooling. The B205 facility constructed at Windscale in the 1960s was dedicated to the reprocessing of Magnox fuels.

Nuclear power was widely regarded in the 1960s and 1970s, especially following the oil import crisis of 1973–74, as the technology that would displace coal- and oil-fired plants in electricity production. Numerous slow-neutron reactors were built around the world, especially using US-origin light-water reactor (LWR) designs. In the UK, Magnox reactors were succeeded by Advanced Gas-Cooled Reactors (AGRs), prior to the adoption of LWRs at Sizewell. But these reactors were considered a transitional phase. The fast-neutron plutonium breeder reactor (FBR) was promoted as the ultimate technology that, through being much more fuel-efficient, would, towards the end of the century, render slow-neutron reactors obsolete. Scientists spoke of an approaching "plutonium economy" and the need to expand plutonium separation via spent fuel reprocessing to prepare for the new energy era. Large stocks of plutonium would be required to provide startup cores for the new reactors.

Utopia for some was dystopia for others. After India had used plutonium from a civil reactor for a nuclear explosive device in 1974, it was feared that a world awash with plutonium would become a world awash with nuclear weapons. During Jimmy Carter's presidency (1977–81), putting an end to reprocessing and fast-neutron reactor programs became a high priority for the US Government. The Carter Administration suspended the United States' own programs and urged other countries to follow suit. Its actions were backed by claims that fast reactors had been oversold, and that storage followed by deep burial of intact spent fuel provided the simplest, safest and cheapest disposal option.

The "Carter Policy" was fiercely resisted abroad. Britain and France, the only other western countries with substantial experience of large-scale reprocessing, sensed an opportunity in the US decision to abandon the practice. In reaction, they drew up plans to construct large reprocessing plants at Sellafield (THORP) and Cap de la Hague (UP3) to reprocess LWR spent fuel from other industrialized countries, especially Japan and Germany, that had ambitions to establish FBR programs but lacked reprocessing capacities. THORP would also be used to reprocess spent fuel from Britain's AGRs, an additional plant (UP2) being constructed by France to serve its much larger fleet of LWRs.

THORP was a technological project embarked upon mainly for economic and security reasons connected to energy supply and industrial gain. The endeavour's record in these terms is considered in the first part of this Report, authored by Martin Forwood and Gordon MacKerron. THORP's operating capacity in terms of spent fuel that was treated the plutonium separated, and its economics, proved to be far below what had been expected by its supporters. The failure of the Sellafield MOX Plant to use the plutonium from THORP to produce mixed uranium-plutonium fuel for power reactors contributed to the accumulation of a large stockpile of UK and foreign owned plutonium to be safely stored and managed with no clear path for its disposition, which is expected to take a long time and be costly. THORP also has left a large and expensive decommissioning challenge and the need to find ways to manage the remaining spent nuclear fuel at the site.

THORP was also a deeply political project from the outset, with serious domestic and international ramifications. This is the subject of the Report's second part, by William Walker. It draws upon his earlier study *Nuclear Entrapment: THORP and the Politics of Commitment* in which he offered five broad admonitions that should be prominently displayed on the office walls of policy-makers faced with decisions on whether to support large projects that bear heavy costs and risks. Although THORP's history has been distinctive, they have universal validity, applying irrespective of country, field of activity and political and economic system:

- Early mistakes can have lasting consequences
- Beware of presumptions to approve
- Understand commitments
- Create and defend diversity and flexibility
- Think about extrication as well as engagement

William Walker

THORP: An Operational History

The reprocessing of spent reactor fuel has been at the heart of Sellafield's operations since 1952 when, in support of the UK's nuclear weapons program, plutonium was recovered from the uranium irradiated in the two Windscale Piles.

After the Windscale accident in 1957, reprocessing at the site moved on to fuel from UK and foreign first-generation Magnox reactors (still ongoing today but due to end in 2020). Trials to reprocess oxide fuel from the second generation Light Water Reactor (LWR) then operating in Europe were held between 1968 and 1973. With just 60 tons* reprocessed, the trial was abandoned in 1973 when a major accident permanently closed the B204 reprocessing plant which had been converted for the trial.

Based on this limited oxide fuel experience, plans had already been drawn up by the state-owned British Nuclear Fuels plc (BNFL) for a new facility that was to capitalise on the worldwide expansion of nuclear power projected in the 1970s. The new facility–The Thermal Oxide Reprocessing Plant (THORP) which would recover plutonium from overseas LWR and UK Advanced Gas Cooled Reactor (AGR) fuel–was designed for use in the then developing Fast Breeder reactor program. Politically much stress was placed by Government and BNFL on the expected profitability of reprocessing Japanese spent fuel. Though highly contested at the 1977 Windscale Public Inquiry, the plans for THORP were approved by the Inquiry and consent for the plant's construction was given by UK Government in 1978.

The construction of THORP began in 1984 and was completed in 1992 at a cost reported (but not independently verifiable) of £2.8 billion in 1989 prices (some £7.8 billion at 2019 prices). Most of this was financed by overseas customers and, in addition, BNFL used its market power (only France offered similar reprocessing services) to impose "cost-plus" contracts on its overseas customers: in other words these customers would have to pay whatever BNFL's operating costs, were plus a margin.[1] Celebrating its construction, THORP and its "re-cycling" technology were described by BNFL as being "the envy of the nuclear nations of the world" and one that would "contribute billions of pounds to Britain's balance of payments, meet the most stringent of safety requirements … ."[2] This was a highly optimistic claim and one that was never borne out, as the expected profit from the first ten years of operation was £500 million.[3] No significant non-UK business was ever won after the contracts signed for the first (notional) ten years.

After further public consultation and legal challenges, Government approval for THORP's operation was given in 1993 and the first spent fuel was sheared in March 1994–by which time the original rationale for THORP had been undermined by the abandonment of the UK Fast Breeder program in the same year. Also, in 1994, Scottish Nuclear (the smaller of the then two UK nuclear utilities) announced that it planned to move to dry storage instead of continued reprocessing of its AGR fuel, which could halve its spent fuel management costs.[4] BNFL re-negotiated its reprocessing contract with Scottish Nuclear at prices that have never been disclosed but were apparently attractive enough for Scottish Nuclear to abandon its storage plans.

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* All tons are metric tons in this report

Figure 1. The Sellafield Site. In operation for over 60 years as part of the UK nuclear weapons and nuclear energy programs, Sellafield has housed over 200 nuclear facilities. It has been owned by the United Kingdom Atomic Energy Authority, then British Nuclear Fuels Limited, and since 2005 by the UK Nuclear Decommissioning Authority. *Source: Global Fissile Material Report 2010 - Balancing the Books: Production and Stocks, IPFM, 2010.*

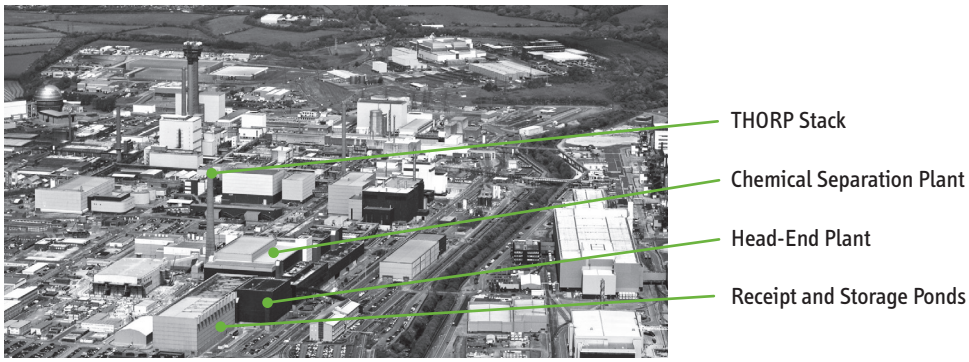

Figure 2. The Thermal Oxide Reprocessing Plant (THORP) at Sellafield. Construction was completed in 1992, operations began in 1994 and the plant began its shutdown in 2018. *Source: BNFL. Reprinted from Martin Forwood, The Legacy of Reprocessing in the United Kingdom, IPFM Research Report No. 5, 2008.*

Performance

With overseas contracts secured by the 1980s, THORP's order book was divided into the Baseload (first 10 years of operation) and post-Baseload period. During the baseload years, the plant was scheduled to reprocess 7000 tons (of heavy metal, tHM) of spent fuel: two-thirds from overseas customers and one-third from the UK's AGR fleet. The post-Baseload order book was dominated by UK AGR fuel, with just one overseas customer (Germany). BNFL remained adamant that THORP would attract additional overseas business but no new orders ever materialized.

Customer	Fuel type	Baseload *tons*	Post-Baseload *tons*
United Kingdom	AGR	2158	2512
Japan	LWR	2673	
Germany	LWR	969	787
Switzerland	LWR	422	
Italy	LWR	143	
Spain	LWR	145	
Sweden	LWR	140	
Netherlands	LWR	53	
Canada (research)	HWM	2	
Reserved		295	
Total		**7000**	**3299**

Table 1. Contracts secured for THORP's Baseload and post-Baseload periods. *Source: BNFL.*

Despite a design throughput capacity of 1200 tHM/year, the plan was to ramp throughput up slowly to 1000 tHM/year for the Baseload, with 850 tHM/year projected for the Post-Baseload period. Given BNFL's limited experience of reprocessing oxide fuel and the technical complexity of a first-of-kind facility, it is not surprising that problems should have dogged Baseload operations, starting with a spillage of nitric acid within a week of opening that led to a closure of almost 3 weeks.

The catalogue of problems that persisted during the Baseload included a range of equipment failures, accidents, pipe leaks and blockages and corrosion problems within the only high-level-waste evaporator configured to serve THORP. Of Sellafield's suite of three Evaporators A, B and C (all of which can serve Magnox reprocessing) THORP was configured for use solely with Evaporator C. Used to volume-reduce reprocessing's high level waste liquors prior to vitrification (glassification), the increasing unreliability of the ageing Evaporators A&B has resulted in the use of Evaporator C being periodically transferred to Magnox reprocessing which was given priority by the safety regulators.

The knock-on effect of these restrictions and unplanned stoppages resulted in a total of just 5045 tHM being reprocessed by THORP by the end of its first 10 years of operation—a significant shortfall from the 7000 tHM originally projected by BNFL. The 7000-ton goal was eventually reached in 2012/13, some 9 years late.

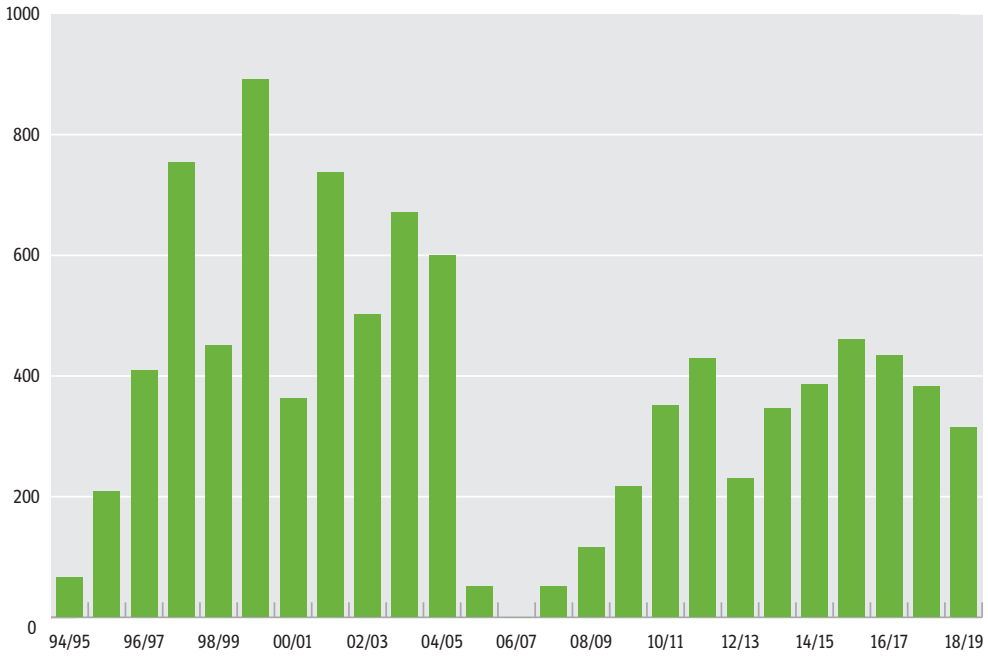

Figure 3. THORP annual throughput in tons of heavy metal (tHM) for Financial Years 1994/95 to 2018/19.

The cancellation of 500 tons of post-Baseload German contracts in 1995 and the failure thereafter to win any new overseas contracts provided the first hint that, approaching the end of the Baseload, overseas customers were not impressed with THORP's progress. At a meeting in 2000, these customers left BNFL in no doubt as to their frustrations over the cost increases being routinely imposed on them which "make it impossible to manage our own fuel cycle business economically." Further, their lack of confidence was "enhanced by BNFL's apparent inability to reprocess our fuel within the agreed baseload period."[5]

The start of THORP's post-Baseload period was marked by two major events. The first was the transfer of ownership of Sellafield (and other UK nuclear sites) on 1 April 2005 to the newly formed Nuclear Decommissioning Authority (NDA).[6] The second was a major accident within THORP just weeks after the NDA took over. On 20 April 2005, it was discovered that 83,000 liters of acid-dissolved fuel had leaked from a fractured pipe serving one of two accountancy tanks in THORP's clarification cell. Rated on the International Nuclear Event Scale as of Level 3 seriousness, a subsequent investigation into the accident found that the leak had probably started in July 2004 under BNFL's stewardship but that instrument warnings had been ignored by the workforce whose "endemic culture believed that, as a new plant, THORP could not leak."[7] In October 2006, BNFL's British Nuclear Group was convicted of breaching site licence conditions and fined £500,000 plus legal costs.

In early 2007, after an assessment on restart/non-restart options by NDA and the UK Health and Safety Executive (HSE),[8] the re-opening of THORP was approved. However, the acid damage to the exterior of one of the two accountancy tanks was such that it had to be permanently withdrawn from service thereby reducing THORP's reprocessing rate by around 50%.

This reduction in post-Baseload throughput rate to well below the planned 850 tons/year level, was exacerbated by the ongoing lack of "evaporative capacity" available to THORP. To overcome the problem, a new Evaporator D, described as being vital for completing THORP's existing contracts, was scheduled to come online around 2010/11 at a cost of £90 million.[9] Delays to the offsite construction of Evaporator D (in modular form) and subsequent delivery to and installation at Sellafield resulted in its physical tie-in to existing facilities being completed only in 2017, and costs that spiraled to £750 million.[10] Active commissioning was scheduled for completion in 2018—some six years late—thereby limiting Evaporator D's use by THORP to the few remaining months of reprocessing before THORP closed at the end of 2018.

From the start of operations in 1994, THORP's performance was far below expectations and plans to close the plant permanently were first laid in 2012 because "it would have taken billions of pounds to upgrade THORP and its support plants to allow it to continue running beyond 2018."[11]

Attempts to produce MOX fuel with the separated plutonium

THORP's operational failure was mirrored within the associated fuel fabrication plant at which the recovered plutonium was to be fabricated into mixed-oxide (MOX) fuel for light water power reactors. With the UK's breeder program shut down in 1994, BNFL had already built an 8 tons/year MOX Demonstration Facility (MDF) which to act as a pre-cursor to the 120 tons/year Sellafield MOX Plant (SMP) in which plutonium recovered by THORP from overseas spent fuel, blended with Magnox-sourced plutonium and depleted uranium, would be converted into fuel for overseas customers.

MDF operated from 1994 to 1999 producing 32 LWR MOX fuel assemblies for Swiss, German and Japanese customers. The sole delivery to Japan—8 PWR MOX fuel assemblies for Takahama's Unit 4 in 1999—was rejected on arrival in Japan when the fuel's quality assurance data was found to have been falsified by MDF workers. The fuel was returned unused to the UK in 2002. Following an investigation into the falsification by the Nuclear Installations Inspectorate, MDF was permanently closed down in 2000.

BNFL claimed that it had "gained experience in MOX fuels, with the manufacture of about 3 tons of MOX for Thermal reactors and over 18 tons for the Fast Breeder program."[12] Construction of the SMP started in 1994 and was completed in 1997. Delayed by subsequent legal challenges and five processes of public consultation, the first MOX fuel was not produced by SMP until 2002.

SMP manifestly failed thereafter to meet projected production targets, and suffered the indignity of having to sub-contract some business to its French rival Areva. It operated until 2011 when, having produced a total of 13.8 tHM of MOX fuel (just over 1% of its design capacity over its operating period), its closure was announced by the NDA.[13]

Financial Year	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
tHM	0.0	0.0	0.3	2.3	2.6	0.0	1.1	4.8	2.7

Table 2. Sellafield MOX Plant production 2002–2011.[14]

The withdrawal of further investment in the plant by Japan, as it grappled with the 2011 Fukushima accident, was cited as being responsible for SMP's closure. A reading of the UK Government's subsequent investigation report into the failure suggests, however, that it was already living on borrowed time. Amongst other failings, SMP as built "was not fit for purpose, [its] culture (as part of the Sellafield site) was not well suited to a precision manufacturing production facility, [it] relied on its relatively limited in house expertise[and it had] an aggregate net total loss for the full plant lifecycle of around £2.2 billion."[15]

Plutonium disposal uncertainty

On completion of its contracts in 2018, subtracting the small quantity converted to MOX in MDF and SMP, THORP was expected to have recovered approximately 56 tons of plutonium.[16] This plutonium was initially labelled as a "zero valued asset," a somewhat problematic concept that seems to have been designed to avoid having to add plutonium disposition costs to the aggregate value of UK nuclear liabilities. Though no breakdown for THORP-recovered plutonium is published in the UK's annual returns published by the Office for Nuclear Regulation (ONR), a figure for overseas-owned plutonium is recorded and, at its peak, stood at 27.9 tons in 2011.[17] Almost all of this stockpile is attributable to THORP.[18]

The reduction to 23.8 tons of overseas-owned material the following year (2012) was accounted for by the transfer to UK-ownership of 4 tons of German-owned plutonium under the first of several "flag-swaps"—an option adopted by Government following SMP's closure.[19] By 2017, further swaps had been made involving a majority of THORP's European customers and resulting in the transfer of 8.5 tons of plutonium to UK ownership.[20] A management decision on the 20.9 tons of Japanese-owned plutonium currently held at Sellafield has yet to be made by Japan, though an offer to take it into UK-ownership, "providing the commercial terms are right," was made in 2012.[21]

The future management of the UK plutonium stockpile, estimated to reached 140 tons by the end of all reprocessing in 2020,[22] has been subject to rounds of public consultation since 2008—with the "credible options" of long-term storage, immobilization as waste and re-use as MOX fuel being assessed.

The Government's preferred option of re-use as MOX fuel was announced in 2011. The NDA first focused on MOX fuel use in new reactors being planned for construction in the UK. When it later became evident that the developers of potential new UK reactors would refuse to use MOX, attention turned to re-use in reactors that would be purchased by the UK government—either CANDU E6 reactors, or GE-Hitachi PRISM fast reactors. Given that immobilization has only been contemplated for the small volume of plutonium "difficult" to use in MOX, NDA decided in 2016 that further decisions on plutonium management would be put on the back-burner until 2025 at the earliest.[23] Very little cost information has been publicly released, but aggregate official estimates suggest that plutonium disposition—by whatever route—will cost a minimum of £2–3 billion to put it into a suitable disposal form. More recent NDA discussions of plutonium disposition options are silent on expected costs.

Decommissioning

For THORP, on completion of fuel shearing in November 2018, all but the Receipt & Storage ponds were to be moved to a Post Operational Clean Out (POCO) phase prior to the plant's decommissioning. Early decommissioning estimates were for a total cost of around £750 million (approximately £2 billion in 2019 money).[24] NDA's most recent estimate (in 2018 money) is £3.7 billion.[25] THORP's ponds however will remain in operation, providing interim storage.[26] They will hold a projected 5400 tons of unreprocessed AGR fuel along with around 30 tons of miscellaneous fuel including spent MOX fuel from Germany and material from the abandoned fast breeder complex at Dounreay, Scotland. A decision is expected over the next decade on whether to continue pond storage in the long-term or transfer the fuel to dry storage.

THORP's unplanned legacy of un-reprocessed fuel and the unresolved management of a plutonium stockpile whose re-use is now shunned by a majority of overseas customers, exposes the misplaced confidence afforded to what BNFL had once described as its "flagship" facility—both in operational and re-cycling terms. On its closure in 2018, when its final overseas contracts were belatedly completed, THORP had reprocessed an estimated 9500 tons of spent fuel over 25 years of operation. The average of 400 tHM/year represents an embarrassingly poor return for a plant designed to reprocess 1200 tHM annually. THORP's routine discharge rates of radioactive materials to sea breach international maritime targets signed up to by the UK two decades ago.[27] These discharges have resulted in levels of contamination to the local environment that continue to raise questions as to their potential impact on the public health of local communities.

With no "balance sheet" yet published for THORP, the plant's net cost is yet to be determined. The early claims from the ex-BNFL Director Harold Bolter that BNFL's figures underpinning the plant's economic case "have turned out to be incorrect in several important respects" and that "if the highly complex plant fails to operate to its projected standard, it will become a huge financial drain on the nation,"[28] suggest the conclusion. When the costs of lost contracts, equipment failures, plant refurbishments, lengthy unplanned outages, escalating decommissioning costs and court fines are added to the mix a negative financial outcome is most probable. A final reckoning, however, has yet to see the light of day.

What is clear is that, despite arguments made by several parties that THORP should either be re-furbished, or a new reprocessing facility built, the UK Government, advised by NDA, has decided that neither of these options will be carried forward. The cost of refurbishment has been officially put at "several billions of UK pounds" and a new plant would probably be even more expensive. But the critical consideration is that there has been no demand for reprocessing services, either from the UK or overseas, for more than two decades. Indeed utilities that are free to make their own decisions on spent fuel management have uniformly decided that storage and direct disposal of spent fuel is their preferred, much cheaper, option.

Martin Forwood and Gordon MacKerron

THORP: A Political History

"You have to realize that it's sometimes right to do the wrong thing." These were the precise words spoken by a friend of the author, an official from the UK's Department of Trade & Industry, when walking down a London street one day in 1993. He was reacting, with a shrug of shoulders, to complaints about the Government's expected decision to allow Sellafield's flagship Thermal Oxide Reprocessing Plant (THORP) to operate. In saying this, he implied that it was correct and responsible for the Government, after taking everything into account, to give political considerations priority when reaching a conclusion. In such a heavily politicized field of activity, political calculation was bound to preoccupy decision-makers, sometimes—as in THORP's case—causing them to maintain support for projects that made little technical and economic sense.

This chapter shows the harm to the public good that came from an attitude that was prevalent in government during most of THORP's history. It gave rise to largely predictable costs and risks that should have been regarded as unacceptable from the outset.

Fifteen years earlier, on 15 May 1978, the House of Commons in Westminster had voted in favor of THORP's construction. Always controversial, the project was promoted as an essential investment that would provide plutonium to fuel a coming generation of nuclear reactors, ease the problems of managing spent nuclear fuel and disposing of radioactive wastes, and bring much commercial benefit to the UK through foreign contracts. Although it was obvious by 1993 that these claims were unfounded, the Government decided to press ahead, hoping but little expecting that all would end well enough, and aware that all might end very badly indeed.

THORP ceased operating in November 2018. In the forty years after its launch, it brought employment and relatively high earnings to West Cumbria, a depressed area of the UK. It was a failure in every other respect. It met few production targets, aggravated waste management, and was a burden, in the UK and abroad, on governments, nuclear power companies and the taxpayers and electricity consumers that ultimately bore its costs. Unhappily, its closure has not been the end of the matter. The task of dealing with THORP's "legacies" (plutonium, radioactive wastes and the contaminated plant itself) and the Sellafield site's various other legacies, and keeping them safe, will last decades, even centuries.

Although short-termism, misjudgment and misconduct contribute to this regrettable outcome, it also arose from cumulative entrapment. Successive governments and industries, not just in the UK, found themselves unable and unwilling to extricate themselves from a project and activity that was putting down deep roots. THORP's story resonates with other cases of entrapment that bedevil societies. Every country has its examples.[29] They have a common pathology. Overselling of benefits and downplaying of costs and complexity. Deliberate embedding of commitments by powerful actors to create irreversibility. Institutional and international entanglement. Neglect of implementation and sidelining of "what if" questions about the future. Absence of exit strategies. And often sheer incompetence.

The telling of THORP's story below is unconventional. It is presented as a drama in three Acts, each with its distinctive scenes, players and locations. This approach has been adopted because it seems truthful to a history that has been theatrical from the outset, its course punctuated by intense public and private struggle to determine the fate of THORP and of the complex arrangements—domestic and international—that developed around it. Act I covers THORP's troubled gestation in the 1970s, including the Windscale Inquiry of 1977 and the first of several parliamentary debates about and votes on its future. Act II is concerned with the completed plant's equally troubled commissioning in the early 1990s followed by the long effort to operate the plant efficiently and deal with its products. This included the unsuccessful attempt to engage in mixed-oxide fuel (MOX) production for foreign customers so that the plutonium could be returned to them encased in reactor fuel. Act III involves the eventual downfall in the 2000s of the project and its main champion and operator, British Nuclear Fuels Ltd (BNFL), and beginning the long and costly effort to deal with its remnants.

Act I. THORP's birth pains

Scene I. Whitehaven, West Cumbria
Peter Shore, Mr. Justice Roger Parker, BNFL, Friends of the Earth

British Nuclear Fuels Ltd (BNFL) was given charge of the Sellafield national reprocessing site in 1971 when the state's nuclear activities were reorganized. It inherited a large facility, B205, for reprocessing Magnox fuel. BNFL soon developed the ambition to establish one and possibly two large plants at which domestic and foreign LWR spent fuel would be reprocessed. It expected to steer the first of these, THORP, through an easily dominated local planning inquiry (plans for a second would eventually be discarded). At the time, however, the UK Government faced a rise in public criticism of its expansionist nuclear policies, exacerbated by expressions of concern over plutonium separation and usage within the highest reaches of the scientific establishment. September 1976 saw the publication of Nuclear Power and the Environment, the Report of an inquiry undertaken by the Royal Commission on Environmental chaired by the distinguished scientist, Sir Brian Flowers. At a public meeting in London shortly before publication, Sir Brian said:

> "We believe that nobody should rely for something as basic as energy on a process that produces in quantity a product as dangerous as plutonium (...) We believe that security arrangements adequate for a fully-developed international plutonium economy would have implications for our society which have not so far been taken into account by the government in deciding whether or not to adopt that form of economy."[30]

The Government was also becoming anxious about the increasingly vigorous campaign of its chief foreign ally, the US, to end plutonium separation for civil purposes, wherever it were being proposed. Before proceeding, a fragile and nervous Labour government needed to find ways of legitimizing its investment in THORP abroad as well as at home.

To the chagrin of BNFL and its supporters in government, the application for planning consent for THORP was therefore "called in" by Peter Shore, Secretary of State for the Environment, and submitted to a national public inquiry. The "Windscale Inquiry" ran from June to November 1977 and was presided over by Mr. Justice Roger Parker (Windscale was renamed Sellafield in 1981). He had chaired the inquiry into the 1974 Flixborough disaster when a chemical factory's explosion killed many workers and devastated nearby villages in Lincolnshire.

Although many groups and individuals gave evidence, the Inquiry turned into a jousting match between BNFL and an international environmental group, Friends of the Earth, ably represented by Walter Patterson and directed, in the UK, by Tom Burke. To the astonishment of THORP's opponents, who believed that they had won the argument by a mile, Mr. Justice Parker dismissed their every objection in his Report and recommended that THORP should proceed without delay.[31] He closed his case with an apparent non-sequitur. "In the light of the foregoing I conclude that reprocessing involving extraction of plutonium is desirable and will be required at some time. I further conclude that if it is to be required at some time there should be no delay in building the plant."

How did "at some time" become "without delay"? Friends of the Earth had argued that reprocessing of spent fuel from UK Advanced Gas-cooled Reactors (AGRs) was unnecessary since—unlike Magnox fuels—they were clad in zirconium alloy, a material that would not corrode in water. In addition, the uranium inside was ceramic oxide, not uranium metal. BNFL responded that studies to demonstrate dry storage of AGR fuel would be expensive and cause much delay, threatening to leave the UK's FBR program short of plutonium after stocks from Magnox reprocessing had been used up. In his Report, Parker gave credence to a scenario envisaging construction of eight FBRs by 2001 (of which the first four reactors would be 1.25 GWe capacity and the others 2.5 GWe each), with two added every year thereafter. This appeared fanciful to anyone familiar with the technology's complexity and immaturity (only a prototype existed) and recalling the troubled history of reactor construction in the UK.[32]

Parker's Report also contained no discussion of BNFL's competence in reprocessing, which was simply assumed. Yet THORP's technology was unfamiliar to BNFL, since it involved AGR and LWR spent fuels, where the uranium was in oxide form which is more challenging to dissolve than the uranium metal in Magnox fuels. Parker dismissed claims that a leap in technology and scale from a 1/5000 scale pilot was unwise. He expressed confidence in BNFL's lead designer, "not only a very impressive witness but one who approached the matter of design with great caution."[33]

Remarkably, the Report gave scant attention to issues relating to reprocessing large quantities of foreign spent fuels—THORP's main purpose—other than to assert that the UK was doing everyone a favor by postponing the establishment of commercial reprocessing elsewhere (THORP was thereby good for nuclear non-proliferation, it was argued). Nothing was said about the security and safety challenges of shipping separated plutonium overseas, which became one of the project's Achilles heels.

An obituarist wrote in 2011 that Sir Roger Parker was "adept at separating what he saw as the rational wheat from the rhetorical chaff."[34] He was not so adept on this occasion. The Windscale Report was a lawyer's creation designed to provide unequivocal support

for a proposal that did not merit it, as he surely knew. Shortly after its publication, Walter Patterson wrote that the Report "bears little relationship to the proceedings of the [Windscale] inquiry. Instead the Report is a heavy-handed nuclear apologia, so clumsily one-sided as to provoke unease even among many Britons previously unmoved by the issue which gave rise to the Inquiry."[35]

Scene II. House of Commons
Peter Shore, David Steel and various MPs

On receiving the Windscale Report in January 1978, Peter Shore took the unusual steps of presenting it for debate in the House of Commons on 22 March and issuing a Special Development Order subject to a "negative resolution procedure."[36] Permission for THORP's go-ahead would be granted unless a motion or "prayer" were tabled against it, triggering a debate and vote in Parliament that would decide the matter. Introducing the Report on behalf of the then Labour Government, Shore thanked Mr. Justice Parker for his "masterly" assessment which he found "cogent and persuasive." The outcome was not in doubt when the Conservative Party's shadow ministers, led by Tom King (Environment) and Michael Heseltine (Trade & Industry), gave their backing. But this did not end opposition in Parliament and the country.

On 15 May, the leader of the Liberal Party, David Steel, presented a motion calling for withdrawal of the Special Development Order.[37] Although the motion was defeated by 224 votes to 80, the desire to avoid an unbreakable commitment in face of uncertainty was a recurrent theme in the parliamentary debate.[38] Recalling the sorry tale of the partnership with France to build the Concorde supersonic transport, Steel warned that "these matters too easily get set on an inflexible and irrevocable course … it is not possible, once we are past this stage, easily for Parliament or future Governments to review [the decision] and draw back." Whilst rejecting Steel's motion, Michael Heseltine called for the House to be "kept informed of the development that will take place between the passage of the Order … and the irreversible decision which [David Steel] assumed would be taken tonight, but which in practice will not be taken for four or five years when the plant's actual construction begins." Winding up for the Government, Energy Secretary Tony Benn assured doubters that "there will be a large number of stages when the House can review the progress of this plant."

In the event, Parliament went to sleep for 15 years and only awoke from its slumbers when BNFL applied for permission to operate the completed plant.

Scene III. Sellafield, capital cities and the High Seas
BNFL, governments and nuclear electricity suppliers, the US and French Navies

With the decision in the bag, BNFL moved quickly to secure contracts with foreign customers, largely on favorable "cost-plus" terms. As noted in the previous chapter, Baseload contracts were signed to reprocess 2673 and 969 tons of Japanese and German spent fuels (in the Japanese case covering the bulk of spent fuel produced in the 1980s). Italian, Spanish, Swedish, Swiss and Dutch utilities signed up for a further 903 tons.[39] Construction of ponds to hold delivered spent fuel began immediately at Sellafield. The contracts were accompanied by confidential intergovernmental agreements setting out terms and expressing support.

THORP was already thoroughly embedded when construction started in 1984:

- By the strength of BNFL's commitment and of its supporters in government;
- By entangling legal contracts and agreements with foreign utilities and governments;
- By the declared support of Cabinet, Parliament, the main political parties and their leaders;
- By the heavy commitment of financial resources, especially from abroad.

But the project's original rationale had already disintegrated. Nuclear power was in the doldrums as costs escalated, glut had replaced scarcity in energy markets, and the frailty of nuclear-power technology was revealed by the accident at Three Mile Island in 1979, followed by Chernobyl in 1986. FBR programs were everywhere scaled back or abandoned (the UK's closed in 1992). Rather than being halted, however, THORP's construction proceeded as if none of this had any relevance.

In 1984 another event spelled trouble ahead. A trial shipment of plutonium travelled from France to Japan via the Panama Canal. In a show of displeasure, the US Government called out the US Navy to accompany the French Navy. Japan was prohibited by its constitution from providing military cover. The option of flying plutonium to Japan was then closed in 1987 by the US Congress's passage of the "Murkowski Amendment" that had the effect of barring plutonium transport through US airspace, Alaska being on the flight path. The next shipment in 1992 had to travel many thousands of miles under military escort—pursued by Greenpeace—down the Atlantic, around South Africa, across the southern Indian Ocean, round Australasia, and up the Pacific Ocean to Japan. All subsequent journeys have followed this route.

The political kerfuffle accompanying these shipments forced London and Paris to concede that plutonium could not be transported in its separated, weapons-usable form. The only option was to ship it embedded with uranium in mixed-oxide (MOX) fuel elements ready for loading into reactors. Materials in this form would require more processing before it could be used for weapons purposes should any state or terrorist group considering hijacking the plutonium en route. Manufacture of MOX fuel required the construction of an entirely new commercial facility at Sellafield, using technology unfamiliar to BNFL. As discussed below, the result was another costly failure.

Act II. Putting and keeping the show on the road, come what may

Scene I. Sellafield, Whitehall and Glasgow
BNFL and Scottish Nuclear

We are now in the early 1990s. John Major's Conservative Government is in office. The UK's electricity industry is in the throes of privatization. Cost and risk reduction are the new priorities. Despite the Windscale Report's talk of urgency, Nuclear Electric and Scottish Nuclear, first inheritors of the state-owned Central Electricity Generating Board's (CEGB's) nuclear power stations after its break-up, had no firm contracts with THORP when its operation was under consideration in 1992–93. Contracts signed by the CEGB in 1986 had been unsettled by privatization. Their replacement was jeopardized by the Treasury's reluctance to underwrite risk.

In 1992, Scottish Nuclear applied for planning permission to construct "dry stores" at the Torness AGR in East Lothian, enabling it to hold spent fuel there for up to 80 years and avoid reprocessing, at an estimated saving of £45 million per year. A public inquiry at Dunbar near Torness gave it the thumbs up. Fearful that Scottish Nuclear's defection would encourage others to follow its example, BNFL and the Government put heavy pressure on the company to abandon its plan, which it duly did.

By the mid-1990s, contracts had been signed to reprocess most of Britain's AGR spent fuel, but with no intention of recycling the separated plutonium. Reprocessing without plutonium usage is essentially a storage policy, the contents of spent fuel being separated just to be stored again, matters made worse by the creation of new waste streams and security requirements. Adding cost rather than value, reprocessing was becoming a supply-driven generator of income and employment for its operator and local region, at public risk and expense. This was far from the future anticipated in 1978.

Scene II. London
John Gummer, Tom Burke, the Cabinet Office, Greenpeace, Lancashire County Council, Mr. Justice Potts

THORP's construction was completed in 1991. The Government was drawn back into the affair by the legal obligation to grant consent for any activity involving discharge of radioactivity into the environment.[40] THORP was receiving much attention in the media, encouraged by a vigorous Greenpeace campaign. Several foreign governments, including the US Government, were also expressing opposition. Without mentioning THORP, President Clinton affirmed that plutonium's "continued production is not justified on economic or security grounds, and its accumulation creates serious proliferation and security dangers."[41] The Treasury also was restive, doubting THORP's economic prospects and lacking confidence in BNFL's financial management.

Unusually, legal responsibility for granting consent lay in person with the Secretaries of State for the Environment and for Agriculture, Fisheries and Food. This forced Michael Howard and his successor John Gummer, in charge of the Department of the Environment in 1992–94, to take a close interest. Tom Burke happened to be their appointed special advisor at the time. Friends of the Earth's UK Director during the Windscale Inquiry, he knew the subject well and had no love of THORP.

Alive to the high stakes, the Cabinet Office convened meetings of senior civil servants between December 1992 and July 1993, seeking interdepartmental agreement on the advice that should be given to the responsible Ministers. At one stage, Burke succeeded in having a "win-win solution" tabled:

- Scrap THORP.
- Instead, store spent fuel delivered to Sellafield, profiting from high storage fees whilst avoiding the cost, risk and hassle of reprocessing and—a vital point—the high cost of dismantling the plant and disposing of residues after the plant had been contaminated with radioactive materials.
- Any plutonium needed for civil purposes could be supplied to foreign customers from Britain's abundant stocks of Magnox-derived plutonium, a proposal also put forward informally by the US Government.[42]

The win-win solution was not taken seriously. Participants could and would not imagine how to disentangle the web of contracts and agreements spun around THORP. Fears were expressed that foreign contractors would cite breach of contract and demand repayment of their shares of the £2.8 billion spent on THORP's construction. Protecting the UK's reputation for commercial reliability was also a concern when Japan was being courted for investment in British automobile and other industries. In addition, the cost-plus contracts signed by foreign utilities were considered to provide the UK with sufficient shelter against cost escalation.

In reality, Japanese and German utilities longed to escape reprocessing and the "plutonium pressure" arising from it. But they too were trapped. Japanese utilities felt compelled to defend reprocessing by their need to transfer spent fuel from reactor sites to storage facilities at Rokkasho-Mura where Japan's own plant was being built (another whole story could be told about this).[43] And German utilities were still required by the German Atomic Law to have all spent fuel reprocessed. This requirement was repealed in 1994 only after THORP's authorization. Long-term storage and disposal of spent fuel in casks became the policy in Germany thereafter.

The Cabinet Office meetings ended with a recommendation to proceed. How to avoid THORP's approval succumbing to legal challenge was already preoccupying the Government. Carefully crafted justifications were published and token public consultations launched. A senior government official later wrote to the author that "The merits of any debate about the benefits or otherwise of continuing with THORP were submerged in considering how to ensure that whatever decision was taken was taken in a process that was legally bullet-proof, and did not set unfortunate precedents." [44]

With Parliament largely submissive, only the law courts stood in the way. On 13 January 1994, Greenpeace and Lancashire County Council were given leave to apply for judicial review of the Ministers' decision.[45] On 4 March, the appointed judge, Mr. Justice Potts, found in the Ministers' favor on all points. "In my judgement the Ministers' approach was neither irrational nor their conclusions perverse … [their] approach to justification cannot be faulted."

Scene III. Sellafield, London, Tokyo, Berlin

THORP began operating in 1994. Designed to reprocess 1200 tons of spent fuel annually, 5000 out of 7000 tons of the original Baseload contracts had been reprocessed ten years later—less than 50% of the design throughput. Subsequent contracts were secured only with British utilities, the one exception being a German post-Baseload contract, two-thirds of which was cancelled in 1995 following the German Atomic Law's amendment in May 1994 to permit long-term spent fuel storage. After much further delay, caused partly by an accident in 2005 that closed the plant for three years and halved its capacity, foreign and domestic contracts were finally completed at the end of 2018 when the plant closed.

Given THORP's anticipated separation of 33 tons of plutonium from foreign spent fuels, including 20 tons of Japanese plutonium, BNFL began construction in 1994 of the Sellafield MOX Plant (SMP) so that plutonium could be shipped back to its owners in the form of mixed-oxide (MOX) fuel. Unlike THORP, the decision to build SMP was not opened to public, parliamentary or departmental scrutiny. A speculative venture

launched with no contracts in hand, BNFL applied to the Environment Agency in November 1996 for consent to operate the plant.

After much toing and froing, the Agency declared in October 1998 that SMP's operation was justified under the law. Fearing that the decision would not survive judicial review, the Government called in the decision on 11 June 1999 and announced a token consultation to provide shelter should a judicial review take place. Its support for the plant, and for THORP's continuation, was evident at the highest level. Two days previously, Prime Minister Tony Blair had told the House of Commons that "I do not support the case of those who would like us to abandon THORP." Earlier in 1999, he had joined forces with Lionel Jospin, France's Prime Minister, to pressure Chancellor Schröder of Germany to overturn his Government's decision to halt all reprocessing of German spent fuels. SMP was approved.

With an estimated cost of £280 million, the Sellafield MOX Plant was designed to produce 120 tons of MOX fuel per year. Output in its first five years of operation was just 5.2 tons. Riddled with technical faults, it closed in 2011 after an expenditure of £1.4 billion, with clean-out and decommissioning predicted to cost a further £0.8 billion. The cost escalation suffered by Sellafield's "Evaporator D" project, to replace a critical component of THORP, was even greater. Estimated to cost £90 million in 2007, its cost had risen to £750 million in 2017 and was still rising.[46]

Act III, without end. The sky falls in on THORP, BNFL and reprocessing

The vision of plutonium-fueled electricity systems, so much part of THORP's justification, had lost sway long before the plant began operating. Worldwide, the less costly and safer technology of dry storage of spent fuel was being adopted. It was symptomatic that, from the 1980s onwards, all nuclear power stations built or planned in the UK, starting with Sizewell B and including Hinkley Point, rely on long-term storage.

By the early 2000s, the longstanding British policy of total reprocessing of spent fuel was giving way to a policy of no reprocessing. The shift was driven partly by consideration of the costs and practicalities, long sidelined, of cleaning up and decommissioning old nuclear sites and facilities and disposing of their radioactive remnants. At the same time, 9/11 made the Government realize, as seldom before, the dangers residing in the UK's nuclear "legacies" should they ever be targeted by terrorists. Well-directed weapons at Sellafield might render significant parts of Ireland and the UK uninhabitable.

In 2002, the Government published a White Paper, *Managing the Nuclear Legacy*. With trust in BNFL's abilities at a low ebb, a new organizational structure was proposed. In 2005, BNFL was dissolved and the Nuclear Decommissioning Authority (NDA) was established, bringing BNFL's various sites and assets under direct government control. Henceforth, the ambition was to return Sellafield to England's green and pleasant land—a fine idea, sustaining employment in the area, that would be expensive to realize. Anticipated costs keep rising. In 2018, the National Audit Office estimated that the undiscounted cost of clean-up and decommissioning at Sellafield would run to £91 billion, assuming completion in 2120. The taxpayer will largely foot the bill.[47]

Rather than stop THORP producing yet more waste and unusable plutonium, NDA—under pressure to generate income and reduce claims on the public purse—decided

to hold its customers to their contracts. THORP lived on, albeit running at half speed because of its technical troubles.

THORP's story did not end when production ceased late in 2018. The task of washing out, dismantling and decommissioning the plant will take decades to complete, its radioactive parts needing reduction to forms capable of eventual burial. Highly radioactive wastes produced by reprocessing are being made safe through incorporation in a glass ("vitrification") held in canisters, again for eventual burial. Despite many studies and a long search, no sites for the underground disposal or medium- and high-level radioactive wastes have been identified and received political approval in the UK. They will be stored above ground for the foreseeable future.

The Windscale Inquiry Report warned of a shortage of plutonium by 2000 with potentially dire consequences for Britain's economy and energy security. Rather than shortage, there has been superabundance. The UK is now home to the world's largest stock of separated civil plutonium, comprising nearly half the world total (about 135 tons out of 280 tons), most of the rest residing in France and Russia. To put this huge stockpile in context, just 3.2 tons of plutonium, derived from early Magnox reprocessing, have been set aside for the British nuclear deterrent. As an average warhead contains less than four kilograms of plutonium, this is more than enough to support a British inventory of about 200 warheads, however long the deterrent is retained.

Around 30 tons of the civil plutonium held at Sellafield have arisen from THORP's reprocessing. It is unlikely to go anywhere. The Fukushima disaster has delayed and reduced plutonium recycling in Japan, and the demise of Sellafield's MOX production has prevented transport of Japan's plutonium in the UK back to Japan. Foreign plutonium seems destined to stay at Sellafield, its ownership gradually transferred to the UK. "Flag-swapping" has already taken place for Germany's plutonium at Sellafield.

What to do with this embarrassing stockpile? As time passes, its usefulness for nuclear fuel will deteriorate due to the unavoidable build-up of radioactive americium within the plutonium, making it tougher to handle and safeguard. Various proposals have issued from the Government, the Royal Society and elsewhere, including the construction—at enormous cost—of special plutonium-burning reactors at Sellafield.[48] None has any momentum. Part of Sellafield may become a nuclear Fort Knox, a plutonium-containing fortress, a no-go area requiring eternal guard.

In 1978 and again in 1993, the what-if question—what will happen if the plutonium produced by THORP finds no use and can go nowhere?—was not addressed by industry or government. Open consideration of such an outcome, and acknowledgement of its plausibility, would be too dangerous for the project.

Lessons

We all make commitments. Societies rest upon commitments that need a degree of entrenchment to take wing. But every commitment is a potential trap, an obstruction, a source of public and private grief if things turn out badly and adjustment brings no relief. The unmaking of commitments is therefore as important as their making if societies are to avoid exposure to serious harm and encumbrance by the debris of past error. This is especially true of ventures like THORP with their potentially grave, long-

lasting consequences. Unhappily, the unmaking of commitments is always difficult, always resisted, and seldom prepared for.

Variety provides one protection against entrapment. Don't put all your eggs in one basket. The story told here began with disregard for this sound old piece of advice. Rather than follow both storage and reprocessing routes, allowing choice between whichever turned out best, the policy and dogma of total reprocessing killed variety. BNFL then invited trouble by building a single reprocessing plant on a huge scale using a technology in which it was inexperienced, a mistake repeated with Sellafield's MOX Plant. The chosen path led its travelers into an overwhelming, entangling complexity and confusion from which there was no easy escape.

Writing in *The Guardian* with Brexit in mind, the political philosopher David Runciman asked whether, given democracy's all too obvious flaws, experts should be left in charge.[49] Shouldn't we follow Plato and let those with knowledge rule for the common good? His answer was no. Runciman distinguished between epistocracy, meaning "rule by the people who know best" and technocracy, meaning "rule by mechanics and engineers [and economists]" who understand "how the machinery works." "What makes epistocracy different is that it prioritizes the "right" decision over the technically correct decision."

Like it or not, experts are bound to dominate nuclear decision-making. The trouble in THORP's case was that the technically incorrect decision was pursued by a frequently deluded, inefficient and self-serving technocracy, its power rooted in an alliance between sections of the state bureaucracy (notably the Department of Trade and Industry) and a state-owned industrial monopoly (BNFL). The epistocracy, if taken (at a stretch) to encompass Parliament and the higher reaches of government, deferred to this technocracy, choosing again and again to accept—touching many bits of wood—that it was "right" to prioritize the incorrect decision. As my friend said, it was right to do the wrong thing.

It was also considered right to pay heed to the wrong experts. Billions of pounds would have been saved and much trouble and danger averted if government and industry had listened to THORP's many critics at home and abroad, including the admirable Janine Allis-Smith and Martin Forwood of Cumbrians Opposed to a Radioactive Environment. But they were usually treated as outsiders, more foes than friends.

William Walker

THORP: A Chronology 1974 to 2018

The following chronology is adapted from William Walker, Nuclear Entrapment: THORP and the Politics of Commitment (Institute for Public Policy Research, London, 1999) and analysis by Martin Forwood, Cumbrians Opposed to a Radioactive Environment (CORE).

1960s/70s American international promotion of nuclear power based on Light Water Reactors (LWR) and dominance of uranium enrichment. US Atomic Energy Commission projects a shortage of low-cost natural uranium and promotes plutonium breeder reactors as the answer.

Early 1970s Nixon administration's proposed privatization of the US enrichment industry, leading to encouragement of plutonium recycling.

1974 UK design studies for oxide reprocessing plant to handle Advanced Gas-cooled Reactor (AGR) and LWR spent fuels.

September 1975 Proposal taken to UK Government, discussed in Cabinet.

March 1976 UK Government's "private" decision to back Thermal Oxide Reprocessing Plant (THORP) at Windscale (later re-named Sellafield), a site in the north-west of England.

1976–1980 Ford and Carter administrations' campaign to end reprocessing, Fast Breeder Reactor development and plutonium recycling. International furor over the Carter Policy.

December 1976 THORP is "called in" and submitted to a public inquiry.

June–November 1977 Windscale Inquiry on THORP chaired by Mr. Justice Parker. Anticipating the need for plutonium to fuel up to eight fast breeder reactors in the UK by 2000, Parker recommends THORP's approval despite strong public criticism.

January 1978 Mr. Justice Parker's Report is presented to the Government.

March 22, 1979 Parliamentary debate on Windscale Inquiry Report.

May 15, 1979 Parliament approves the Special Development Order granting British Nuclear Fuels Ltd (BNFL) outline planning permission for THORP's construction.

1978–81 Base-load contracts are signed by BNFL and foreign utilities. Their spent fuels begin to be delivered to Sellafield.

1980 Government instructs BNFL to improve its management and safety standards.

1983 Full planning permission is granted for THORP's construction.

1984 Shipment of 253 kilograms of plutonium from France to Japan via the Panama Canal, escorted by the US and French navies.

1986 The UK's Central Electricity Generating Board (CEGB) signs cost-plus reprocessing contracts for THORP.

1988–90 First privatization of the British electricity supply industry.

1988 Renegotiation of US-Japan Nuclear Co-operation Agreement completed, gives Japan prior consent to reprocess spent nuclear fuel (case-by-case Congressional approval was no required).

1989 Germany abandons the Wackersdorf reprocessing plant.

1990 Government announces closure of Britain's fast reactor program.

1991 THORP's construction is completed.

1992–97 Phased second privatization of the electricity supply industry.

Early 1992 The UK Treasury rejects proposed fixed-price reprocessing contracts between BNFL and Nuclear Electric and Scottish Nuclear, operators of the UK's nuclear power stations.

April 1992 BNFL applies to Her Majesty's Inspectorate of Pollution (HMIP) for authorization to commission THORP and begin operation.

October 1992 Greenpeace seeks legal opinion on requesting judicial review of THORP's authorization.

November 1992 Initiation of 10-week public consultation on HMIP'S draft authorization.

November 1992 Controversial shipment of 1.2 tons of plutonium from France to Japan, escorted by adapted Japanese coastguard vessel.

December 1992 to July 1993 Meetings of the Cabinet Office's "Committee" on THORP.

June 16, 1993 The Paris Commission (PARCOM) that administered the 1978 Convention on the Prevention of Marine Pollution from Land-Based Sources (Paris Convention) voted for wider justification of THORP.

June 28 1993 Liberal Democratic Party's motion against THORP is voted down in Parliament.

July 1993 Publication of Government Statement on Reprocessing and on THORP; and of BNFL's Economic and Commercial Justification of THORP.

August 1993 Second public consultation is called by the UK Government.

September 1993 US Congressmen's letter to President Clinton; Clinton's response that continued plutonium production for civil purposes was not justified.

December 15, 1993 John Gummer, Secretary of State for the Environment, informs Parliament of his decision to authorize THORP's operation.

January–March 1994 Lancashire County Council and Greenpeace initiate a Judicial Review of the Ministerial decision on THORP; Mr. Justice Potts rules in the Government's favor; THORP is approved.

Spring 1994 The commissioning of THORP begins.

May 1994 Amendment of the German Atomic Law enables long-term spent fuel storage.

Autumn 1994 BNFL begins construction of Sellafield MOX Plant (SMP) after realizing that plutonium can only henceforth be transported to foreign customers in MOX fuel.

December 1995 Accident at the Monju fast reactor in Japan.

November 1996 BNFL applies to UK Environment Agency for permission to operate the SMP facility.

March 1997 Nirex's application for planning consent for the Rock Characterization Facility at Longlands Farm, concerning Sellafield's appropriateness for underground waste disposal, is rejected by John Gummer.

October 1998 Environment Agency recommends authorization of SMP's operation but invites Government to "call in" the decision.

April 1998–January 1999 Problems with pipe blockages impede reprocessing of AGR fuel.

January 1999 German Government announces ending of civil reprocessing of German fuels in Britain and France, then changes its mind under pressure from Prime Ministers Tony Blair and Lionel Jospin.

March 1999 Publication of House of Lords Select Committee's Report on Management of Nuclear Waste.

June 1999 John Prescott, Secretary of State for the Environment, announces that the Government is minded to authorize SMP's operation, but opens another public consultation on economic issues.

Summer 1999 Government announces that it will seek a "public-private partnership" in BNFL through its partial privatization.

Summer 1999 Joint shipment of MOX fuel from Britain and France to Japan.

November 2001 British Energy, the UK's sole nuclear utility, calls for a moratorium on any future reprocessing of its AGR reactor fuel, asserting that there was no technical requirement to reprocess the fuel. BNFL's technical bankruptcy announced by Secretary of State for Trade and Industry.

March 2003 Overseas customers threaten to pull out of their contracts with THORP because of BNFL's attempts to impose stringent 'cost-escalating adjustments' to their contracts.

March 2004 End of "Baseload" period of first ten years of operation, by which time 7,000 tons of fuel were planned to be reprocessed. Instead only 5045 tons had been reprocessed by this time, and the Baseload volume of 7000 tons was only completed in 2012/13, some 3 years late.

April 2005 Nuclear Decommissioning Authority (NDA) takes over Sellafield, THORP and other sites. BNFL is dissolved.

April 2005 INES Level 3 accident in THORP Clarification Cell. Leakage of 83,000 liters of dissolved fuel (22 tons). Irreparable acid damage to one of two Accountancy Tanks in the Cell.

August 2011 Closure of the Sellafield MOX Plant. Designed to manufacture 120 tons of MOX fuel per year, it produced only 13.8 tons over its lifetime.

November 2011 NDA paper on future of THORP reprocessing selects, as preferred option for THORP, to "finish contracts" rather than options of early plant closure or extension to reprocessing operations.

2012 Sellafield announcement of THORP closure in 2018 "with current contracts complete."

November 2016 Target to complete all overseas contracts missed.

April 2017 Sellafield Ltd. publishes plans for the long-term storage of an estimated 5500 tons of AGR fuel spent fuel in THORP ponds (B560), and Post Operative Clean Out (POCO) of THORP.

November 2018 Final shearing of spent fuel in THORP begins on 9 November 2018. On completion, the plant had reprocessed a total of 9331 tons of spent fuel. The initial contracted order book secured in 1994 at THORP's opening was 10,229 tons.

Post–Nov 2018 Thorp Head End and Chemical Separation plant will transition immediately to a managed Post Operative Clean Out (POCO) which is expected to take 3–5 years.

Endnotes

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2 British Nuclear Fuels Limited, Press Release, 4 March 1992.

3 "The profitability of THORP" presentation by K. G, Jackson, Director, THORP Division, British Nuclear Fuels plc, 7 November 1990.

4 C. J. Bagun , R. V. Killingley, D. Anderson, and S. R. Donald, "Licensing approach and progress for the Scottish Nuclear dry stores at Torness and Hunterston" British Nuclear Energy Society Conference, 20–22 March 1995.

5 Minutes (leaked) of Overseas Baseload Customers meeting with British Nuclear Fuels Limited, London, 18 September 2000.

6 Formed under the 2004 Energy Act, the Nuclear Decommissioning Authority replaced the technically bankrupt British Nuclear Fuels Limited.

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37 The centrist Liberal Party (now called the Liberal Democratic Party) has usually attracted between a tenth and fifth of votes cast in general elections in recent decades. It has nevertheless been underrepresented in Parliament due to the UK's first-past-the-post electoral system. The Party has traditionally been sceptical of the benefits and safety of nuclear power.

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