MACHIEL KLEEMANS*

Secrecy and the Genesis of the 1951 Dutch-Norwegian Nuclear Reactor

ABSTRACT

Despite the restrictions on knowledge and materials of the Anglo-American nuclear monopoly in the early Cold War, Norway and the Netherlands managed to build and operate a joint nuclear reactor by July 1951. They were the first countries to do so after the Great Powers. Their success was largely due to the combination of the strategic materials of heavy water (Norway) and uranium (the Netherlands). Nonetheless, they had to overcome significant political and technical obstacles. In that process a number of specific nuclear secrets played a central role. This case is used to study how and why knowledge circulation was impeded by secrecy. Specifically, I will explore four different secrets that illustrate how the Netherlands and Norway, being outside the British and American secrecy regimes, chafed against those regimes. Knowledge circulation was enabled through relations within networks that were at the same time scientific, diplomatic, and personal. I will identify three main factors that affected the mobility of information: the availability of strategic nuclear materials, the scientists' individual interactions, and national interests.

KEY WORDS: nuclear secrecy, Cold War Science, uranium, heavy water, Hendrik Kramers, Gunnar Randers, Norway, the Netherlands

*Vossius Center for the History of the Humanities and Sciences, University of Amsterdam, Science Park 904, 1098 XH, the Netherlands; machiel.kleemans@kpnmail.nl.

The following abbreviations and acronyms are used: FOM, Fundamenteel Onderzoek der Materie; FRUS, Foreign Relations of the Unites States (http://history.state.gov); JEEP, Joint Establishment Experimental Pile; NA, Nationaal Archief, The Hague, the Netherlands; NHA, Noord-Hollands Archief, Haarlem, the Netherlands; NNA, Norwegian National Archives, Oslo, Norway; TNA, The National Archives, Kew Gardens, Richmond, United Kingdom; ZEEP, Zero Energy Experimental Pile.

Historical Studies in the Natural Sciences, Vol. 51, Number 1, pps. 48–86. ISSN 1939-1811, electronic ISSN 1939-182X. DOI: https://doi.org/10.1525/hsns.2021.51.1.48.

INTRODUCTION

The role of nuclear physics in the twentieth century perhaps best illustrates Francis Bacon's phrase "knowledge is power." Its rapid development during World War II in the Manhattan Project led to the construction of the first nuclear weapons in the summer of 1945. Those who had developed the knowledge and technology that wielded this unprecedented power felt they were well worth protecting. The facts that the science and technology were so new, and were developed in great secrecy, suggested to some that the imposition of secrecy could help to protect the nuclear monopoly.[1] Well before the end of the war, the Manhattan Project partners set out to create the conditions for a sustainable postwar nuclear monopoly. Their most important tools were restrictions on the circulation of "strategic materials" such as uranium and the control of knowledge through secrecy regimes. In December 1945, General Leslie Groves, the wartime leader of the Manhattan Project, estimated that 97 percent of the estimated global uranium output was under Anglo-American control.[2] Nuclear technology and knowledge were also controlled through strict policies of secrecy. These restrictive measures, however, had neither total nor global reach. Besides the covert nuclear program in the Soviet Union, a few countries in Europe commanded relevant materials and knowledge.

Scientists and engineers in Norway had been the first to produce heavy water on an industrial scale before the war. Heavy water proved to be an important neutron moderator for nuclear reactors, and thus a key strategic material. After the war, Norway initially remained its sole producer outside North America, where a domestic capacity was developed. The most important nuclear material, uranium, also was available in some small but significant quantities in Europe after the war. Dutch scientists, together with state officials, had covertly acquired ten tons of uranium oxide in April 1939. They kept knowledge of the acquisition to themselves, and thereby held on to the uranium after the war had ended. In France, comparable amounts of uranium that had been hidden, emerged after the war and proved sufficient to start a modest reactor program. The availability of these strategic materials was one reason that France, the Netherlands, and Norway were the first countries in Europe

1. Michael Aaron Dennis, "Secrecy and Science Revisited—From Politics to Historical Practice and Back" in *Secrecy and Knowledge Production*, ed. Judith Reppy, Cornell Peace Studies Program, Occasional Paper #23 (Ithaca, NY: Cornell University, 1999, 1–16, on 8.

2. Michael D. Gordin, *Red Cloud at Dawn—Truman, Stalin and the End of the Atomic Monopoly* (New York: Picador, 2009), 73.

(apart from Britain) to start reactor programs. The first reactor in France went critical in 1948; Norway and the Netherlands followed with a joint reactor in July 1951.

The Dutch-Norwegian reactor was the only reactor outside of the Great Powers that was entirely constructed while the full restrictions on knowledge and materials of the Anglo-American nuclear monopoly were in place.[3] These restrictions were only relaxed after President Dwight Eisenhower announced the Atoms for Peace program in December 1953. Atoms for Peace provided other countries with access to nuclear materials and technology as well. The Dutch-Norwegian reactor is therefore an interesting case that illustrates how limitations on the circulation of knowledge and materials worked before reactor technology was declassified on a major scale.

This subject resonates with what Jim Secord has identified as a central question in history of science: How and why does knowledge circulate?[4] I will consider a negative formulation of this question: How and why is the movement of knowledge impeded? This is a similar approach to that taken in recent work by John Krige and others, which challenges the idea that "knowledge simply moves across borders without friction in a 'flat' networked world." These studies "problematize circulation itself" and "emphasize the social and material constraints that *impede* the movement of knowledge across borders."[5] I will examine four specific secrets that illustrate how scientists and politicians in the Netherlands and Norway, being outside the British and American secrecy regimes, chafed against those regimes and tried to get access to them.

The four secrets concern information that at different times and places were or were not supposed to remain secret. I generally refer to "secrecy" as the term was used and understood by scientists and state officials in Norway and the Netherlands in the timeframe of this history, 1939–1951. A precise use of terminology is complicated somewhat as the terms can be used differently in English and Dutch. The English word "secret" translates directly to the Dutch word "geheim," but "geheim" can also refer to "classified" or "covert." In Dutch, "geheim" is often used rather loosely, and this was especially the case in the early years of the Cold War. Incidentally, the Norwegian word for "secret" is "hemmelig," cognate with the Dutch word "heimelijk," which is

3. Sweden also started an early heavy water reactor project before Atoms for Peace, but its reactor only went critical on July 13, 1954, three years after the Dutch-Norwegian reactor.

4. James A. Secord, "Knowledge in Transit," *Isis* 95, (2004): 654–72.

5. John Krige, ed., *How knowledge moves: Writing the transnational history of science and technology* (Chicago: University of Chicago Press, 2019), 2–3.

related to "geheim." The word "heimelijk" can be translated as "secret" but is closer to "sneaky" or "surreptitious." In any case, the four secrets under discussion were not all secrets in a formal sense, ranging from a gentlemen's agreement between Dutch scientists to not talk about their uranium supply to formally classified data in the UK about the production of uranium metal.

Controls on knowledge circulation are neither perfect nor permanent: "The arsenal of knowledge is surrounded by walls that are carefully guarded, but that are irreducibly permeable. [. . .] Formal mechanisms for protecting proprietary knowledge are repeatedly subverted by semiformal and informal procedures, including leaks to the press, scientific intelligence gathering and espionage."[6] A study of this permeability may provide a novel perspective on the how and why of knowledge circulation. I will argue that the three main factors that influenced the (im)mobility of information were: the need for strategic materials, interpersonal contacts between scientists, and the consideration of national interests.

The Dutch-Norwegian collaboration was by no means an exclusively bilateral affair. In order to overcome all technical and political obstacles, Norway and the Netherlands relied significantly on other countries, especially England, France, and to a lesser extent on the United States. These countries each had their own nuclear interests that did not always coincide. Between 1945 and 1950, Norway tried at various stages to align its nuclear program with each of these countries. The reactor ultimately ended up with Norwegian heavy water, French reflector graphite, a largely French reactor design, Dutch uranium, and critical British support by trading Dutch uranium oxide for metallic uranium fuel elements. All this eventually received the reluctant blessing of the United States as Norway and the Netherlands were seen as "the best of the lot" (i.e., European countries).

The economic and military power promise of nuclear physics quickly caught the attention of the state, but state officials depended on scientists to understand the new science and its implications. On the other hand, nuclear scientists needed the government's financial and administrative support to develop the large-scale facilities they required. This mutual dependence led to a close working relationship between science and the state during the war that only intensified after it ended. Both scientists and state officials recognized a need for secrecy but generally weighed their interests and principles differently. Although the scientists often took the lead in proposing limitations on

6. John Krige, "Building the Arsenal of Knowledge," *Centaurus* 52 (2010): 280–96, on 282.

sharing of information, they needed the state to implement effective controls on knowledge circulation. Nuclear knowledge control was typically co-constructed by scientists and state officials.

In the early 1990s a number of important studies on the Dutch-Norwegian collaboration were published.[7] These studies largely explored political science and international relations perspectives. The subject recently has found itself again in the focus of attention within the history of science.[8] As a case study, it provides another example of the shift in historiographical perspective of Cold War Science toward transnational developments and how these shaped local decisions. A collection of essays on *Cold War Science and the Transatlantic Circulation of Knowledge*, which was published in 2015, centered on the question: "How did specific conditions of the Cold War, such as secrecy and a strong military interest in science, affect both the transatlantic and the intra-European circulation of knowledge?"[9] The question was posed with particular focus on small European nations such as Denmark and the Netherlands. This article gives a partial response to that question. As a very early Cold War case, however, America's hegemonic influence was expressed by an attitude of monopolizing rather than sharing nuclear knowledge. With their joint reactor program, the Netherlands and Norway responded to this attitude and created conditions for a future, more open exchange.

In this article, I will examine four specific secrets and their relation to the Dutch-Norwegian nuclear project: (1) the number of fission neutrons of uranium-235, (2) Dutch possession of uranium, (3) reactor design, and (4) the

7. Most notably by Astrid Forland and Olav Njølstad for Norway and Jaap van Splunter for the Dutch case: Astrid Forland, "På leiting etter uran, Institutt for Atomenergi og internasjonalt samarbeid 1945–51," *Forsvarsstudier* (Oslo, Institutt for Forsvarstudier) 3 (1987); Olav Njølstad, *Strålende Forskning—Institutt for energiteknikk 1948–1998* (Tano Aschehoug, 1999); J. M. van Splunter, *Kernsplijting en diplomatie—De Nederlandse politiek ten aanzien van de vreedzame toepassing van kernenergie, 1939–1957* (Amsterdam: Het Spinhuis, 1993); J. M. van Splunter, "Love at first sight, Co-operation between the Netherlands and Norway on the peaceful use of atomic energy, 1950–1960," *IFS Info*, no. 2 (1994).

8. F. Hoeneveld, *Een vinger in de Amerikaanse pap. Fundamenteel fysisch en defensie onderzoek in Nederland tijdens de vroege Koude Oorlog* (PhD thesis, Utrecht University, 2018); Friso Hoeneveld and Jeroen van Dongen, "Out of a Clear Blue Sky? FOM, The Bomb, and The Boost in Dutch Physics Funding after World War II," *Centaurus* 55, no. 3 (2013): 264–93; Abel Streefland, *Jaap Kistemaker en uraniumverrijking in Nederland 1945–1962* (Amsterdam: Prometheus, 2017); Cees Wiebes, *Samen met de CIA. Operaties achter het ijzeren gordijn* (Amsterdam: Boom, 2016).

9. Jeroen van Dongen, Friso Hoeneveld, and Abel Streefland, "Introduction," in *Cold War Science and the Transatlantic Circulation of Knowledge* ed. Jeroen van Dongen (Leiden: Brill, 2015), 1–7, on 2.

uranium metallurgy process. These secrets will appear in roughly chronological order.

A CLASSIFIED NUMBER AND A COVERT ACQUISITION

In December 1938, Otto Hahn, Fritz Strassmann, and Lise Meitner discovered that uranium could fission when bombarded with neutrons, releasing a huge amount of energy that had been locked in the atomic nucleus. But in order to generate energy on a macroscopic scale, a chain reaction of rapidly fissioning nuclei was required. The feasibility of a chain reaction in uranium came down to a crucial number that had yet to be determined: the number of neutrons released when the uranium nucleus fissions. The more neutrons that emerge from fission, the more new fissions can occur and the easier it is to establish a chain reaction. The average number of fission neutrons—also referred to as "secondary neutrons"—is typically called "ν."

The history of the discovery of fission neutrons is well known and has been reported, for instance, by Spencer Weart.[10] By April 1939, goups in Paris (under Frederic Joliot-Curie) and New York (including Enrico Fermi and Leo Szilard) discovered that ν appeared large enough to make a chain reaction in uranium at least a theoretical possibility. Szilard, the Hungarian physicist, had been concerned about the potential of nuclear energy for a long time. In one of the earliest debates on nuclear secrecy, he worried about whom to include in the sharing of new and sensitive knowledge. He proposed that knowledge circulation should be restricted and that "results would be communicated in manuscripts to cooperating laboratories in America, England, France and Denmark."[11] The Netherlands and Norway were not on the list. Szilard's proposal to implement a secrecy regime voluntarily by the physics community itself failed, but a more successful regime soon developed, when governments in Britain and the United States introduced formal secrecy policies. Dutch and Norwegian scientists, however, had early personal interactions with Joliot-Curie and Fermi, respectively, before and during WWII, which, as I will show below, opened up windows of opportunity that otherwise might well have been closed.

10. Spencer R. Weart, *Scientists in Power* (Cambridge, MA: Harvard University Press, 1979), 75–92.

11. Spencer R. Weart, "Scientists with a secret," *Physics Today* (Feb 1976): 25.

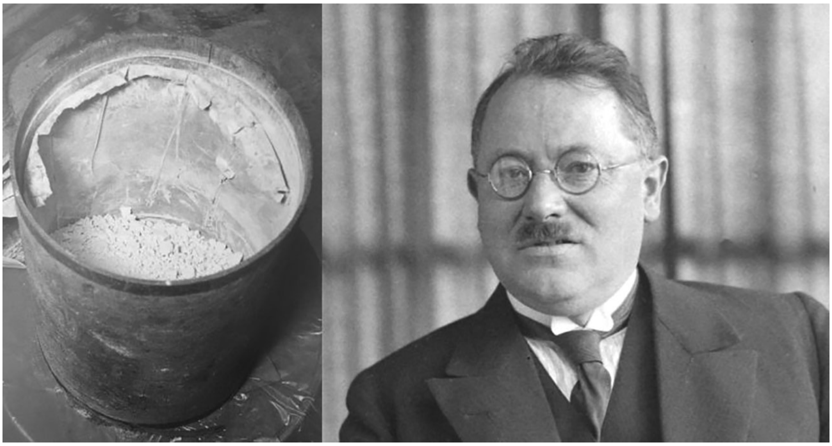

FIGURE 1. Left: Original pre-war container with Dutch yellowcake. *Source*: NRG (former ECN-RCN) photo archive. Right: Wander de Haas. *Source:* Leiden Institute of Physics; used with permission.

The precise number of fission neutrons was classified during the war and remained officially classified until 1950. This was an important number because the size of a critical mass, both for reactors and for nuclear weapons, depends sensitively on it. Norwegian scientists needed and obtained it to make an early, informed decision in 1946 about the feasibility of a reactor program.

Dutch Acquisition of Uranium

Just as the discussion of knowledge limitation was getting underway, in April 1939, Dutch physicist Eliza Wiersma was visiting Joliot-Curie's group in Paris, with whom he discussed their efforts to produce a chain reaction in uranium.[12] Upon his return to the Netherlands, Wiersma conferred with Wander de Haas, co-director of the Kamerlingh Onnes Laboratory for Physics in Leiden (see Fig. 1). De Haas, who was well connected in both scientific and political circles, recognized the strategic importance of the French results. That same month, he approached the Minister of War, Jannes J. C. van Dijk, and one day later sat down with Van Dijk, Prime Minister H. A. Colijn, and Minister of Economic Affairs Max Steenberghe.[13] De Haas explained the potential

12. H. B. G. Casimir, *Haphazard Reality* (New York: Harper & Row Publishers Inc., 1983), 173; D. van Delft, "Tegen de roof: het Kamerlingh Onnes laboratorium in oorlogstijd," *Gewina* 30 (2007): 247–64.

13. Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 27.

military use of uranium and convinced Colijn to covertly buy a significant quantity of uranium, in part to keep it out of German hands.[14,15] Dutch parliament was not informed. Under the guise of "yellow pigment" for the Dutch glass factories, ten tons of yellowcake was covertly acquired from the Union Minière in the Belgian Congo. Its purported aim was coloring glass, which until that time was uranium's most common application. The decision to acquire the uranium covertly was effectively a joint decision, sharing the "ownership" of the secret between the scientists and politicians involved.

It is a case of counterfactual history what would have happened had the French agreed to Szilard's proposal to postpone publication. The Netherlands was not on the list of countries that Szilard proposed to Joliot. Had the French agreed, they might not have shared their latest results with Wiersma, whose information resulted in the early Dutch acquisition of yellowcake. It is plausible, however, that the early interaction between the French and the Dutch—Joliot and Wiersma—and the quick follow-up by the latter, enabled an early acquisition of uranium just before its nuclear potential became more widely known. The purported aim of coloring glass was entirely credible and apparently not interpreted by anyone in a nuclear context. French and English scientists only notified the president of the Union Minière in the Belgian Congo, Edgar Sengier, of the new potential of uranium in May, weeks after the Dutch order.

The uranium that was delivered to the Netherlands came in 200 containers of 50 kg each that were initially stored at the University of Leiden[16] (see also Fig. 1). De Haas soon realized that the ionization caused by its radioactivity would hamper experiments at the lab and that the uranium should be moved elsewhere.[17] As the war approached, it was sent to the Technical University in Delft, where it was hidden in a basement. There it remained hidden from the German authorities during the occupation of the Netherlands.

The bombing of Hiroshima in August 1945 revealed perhaps the biggest nuclear secret: that a deliverable nuclear weapon could indeed be built. The news also led to a breach of secrecy regarding the Dutch uranium stock. In

14. J. A. Goedkoop, *Geschiedenis van de Noors-Nederlandse samenwerking op het gebied van kernenergie*, Mededeling nr. 30 (Reactor Centrum Nederland, Petten, 1967).

15. H. M. Hirschfeld, *Herinneringen uit de bezettingstijd* (Amsterdam: Elsevier, 1960), 206.

16. Van Splunter, *Kernsplijting en diplomatie* (ref. 7) 31; J. A. Goedkoop, *Een kernreactor bouwen: geschiedenis van de Stichting Energieonderzoek Centrum Nederland* (Beta Tekst, Bergen, 1995), 6.

17. Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 32.

a Dutch newspaper comment on the Hiroshima bomb, De Haas briefly mentioned the Dutch uranium supply.[18] This bit of information was, however, not picked up by the Allies or even by Dutch politicians. Shortly thereafter, it was decided that the Dutch uranium supply should remain secret, and it was given the code-name "hexa."[19] Dutch officials endeavored to keep the supply secret until 1950 in order to retain a certain independence from the monopolizing countries and until they could actually use it. It then became the saving "life buoy" of the struggling Norwegian nuclear program and key to a joint project.

POST-WAR SCIENCE IN THE NETHERLANDS AND NORWAY—KRAMERS AND RANDERS

Two other secret technologies that were important for the Dutch-Norwegian nuclear project—reactor design and production technology for uranium metal—were largely developed during and after the war. Before introducing these I will first discuss nuclear ambitions and their rationale in the Netherlands and Norway in the immediate post-war period.

In the occupied countries of Europe, science largely ground to a halt during the war. After the war, these countries focused first on restructuring their economies and political culture. With the US emerging as the single Western superpower, many countries in Europe came to depend to various degrees on the American hegemon for their post-war development. This served American interests as well.[20] After the rapid development of nuclear physics in America, it was clear to these European countries that science and nuclear physics in particular would play a prominent role. In the Netherlands, a leading role in reconstituting science fell to the eminent physicist Hendrik ("Hans") Kramers. In Norway, the young astrophysicist Gunnar Randers took up a similar role. Together, these two men were central in the success of Dutch-Norwegian collaboration, and I will briefly introduce them here.

18. Ministerie van Marine, *Het bombardement der Uraanatomen*, NA inventory number 7831, early August 1945. Exact date and newspaper are not known, but given the advertisements for events on the 10th of August 1945, and the lack of reference to the second bomb, a probable publication date lies around August 8, 1945; Hoeneveld, *Een vinger in* (ref. 8), 371.

19. The code name may refer to the fact that the uranium was in the form of UO_3, which is called the "hexavalent oxide" of uranium.

20. J. Krige, *American Hegemony and the Postwar Reconstruction of Science in Europe* (Cambridge, MA: MIT Press, 2006).

Although quite different in character and accomplishments, they had both developed an impressive international network. That was important in two ways: in the case of Randers, his contacts were instrumental in acquiring secret nuclear information; in the case of Kramers, they helped to inspire confidence in political leaders that this sensitive nuclear project was in trusted hands. Kramers was trusted to such a degree that he was allowed to discuss the secret uranium supply at his own discretion. This forged a quick breakthrough with Norway in 1950.

John Krige has noted that "transnational history tends to celebrate the 'fluid', 'hybrid' identities assumed by people who are transformed by their engagements with different cultures and ways of life."[21] As is evident from their introduction below, both Randers and Kramers had assumed such hybrid identities: they had had extensive engagement with different scientific cultures from the start in their careers, which helped them to successfully realize the transnational movement of nuclear knowledge and materials.

Hendrik Kramers

Hendrik Anthony Kramers (1894–1952) is perhaps best known for his work with Niels Bohr in Copenhagen on quantum mechanics in the early 1920s. Kramers had been Bohr's first assistant; Wolfgang Pauli famously declared that "Bohr is Allah and Kramers is his prophet."[22] In 1925, Kramers returned to the Netherlands to accept a chair in Physics at the University of Utrecht. While there, he mentored a young Robert Oppenheimer in 1928, who was then touring Europe. They shared a similar, somewhat formal, approach to physics and would remain in close contact until Kramers died in 1952.

In 1934, Kramers had taken up the physics chair in Leiden, filling the void left by Paul Ehrenfest's suicide. After the German occupation of the Netherlands ended, his reputation and network made Kramers the obvious person to lead the restoration of physics in the Netherlands. In 1945, he became president of the Dutch Commission for Atomic Physics. The task of the Commission was to develop a vision regarding nuclear physics in the Netherlands.[23] Then, in April 1946, he became the first director of the post-war Dutch research

21. Krige, *How knowledge moves* (ref. 5), 12.

22. Ray Monk, *Inside the Centre—The Life of J. Robert Oppenheimer* (New York: Vintage Books, 2013), 154.

23. As referred to in: Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 36; Notulen van de vergadering van de adviescommissie voor Kernphysica, 3 Nov 1945, NHA, FOM, 449/

organization FOM (Fundamenteel Onderzoek der Materie, or Fundamental Research of Matter), which was then primarily aimed at getting Dutch nuclear research off the ground.

Shortly after the war, in October 1945, Kramers visited Niels Bohr in Copenhagen, who gave him a copy of the Smyth Report. The report gave a semi-technical account of the development of nuclear weapons in the Manhattan Project. In the words of Richard Hewlett, chief historian of the US Atomic Energy Commission, it was "a general description of the organizational and scientific principles used to produce the bomb [. . .] but every technical specification of the process remained classified, including even the fundamental physical properties of the heavy elements."[24] From reading the Smyth Report, by November 1945, the Dutch Commission got the impression that in the US "no new scientific perspectives had been developed."[25] They were strengthened in this belief by messages coming out of the US from former colleagues. Pauli, for instance, who had worked in Princeton during the war, cautioned against disappointment in Holland when the American and British journals would arrive: "A few weeks will be sufficient for you and others to learn everything of scientific interest which happened during these 'lost years'."[26] The Smyth Report also clarified the huge industrial scale of the Manhattan Project. As Kramers mentioned in the Commission: "The Smyth Report demonstrated that one should not make illusions about competing or imitating."[27] The Commission agreed that a military nuclear program would require a technical and financial effort the Netherlands could not afford. They also agreed that the Netherlands should not consider it its task to develop nuclear technology for military purposes. They should even avoid the impression of thinking about military applications.[28] Kramers calmed fears that a large investment would turn out to be wasted once the Americans would publish

378; Hoeneveld and Van Dongen, "Out of a Clear Blue Sky?" (ref. 8); Hoeneveld, *Een vinger in* (ref. 8), 115.

24. Richard G. Hewlett, "A historian's view," *The Bulletin of the Atomic Scientists*, (Dec 1981): 20.

25. Notulen van de vergadering van de adviescommissie voor Kernphysica, 3 Nov 1945, NHA, FOM, 449/378.

26. W. Pauli to H. B. G. Casimir, 11 Oct 1945, CERN, Pauli Letter Collection, https://cds.cern.ch/record/83461/files/casimir_0035-5. "You and others" probably included Kramers, after whom Pauli inquires a bit later in this letter.

27. As quoted in Hoeneveld, *Een vinger in* (ref. 8), 166.

28. Notulen van de vergadering van de adviescommissie voor Kernphysica, 3 Nov 1945, NHA, FOM, 449/378.

their secret results. He did not think the American would give up their secrets anytime soon.

Regarding secrecy, Gilles Holst advised the Commission, at its second meeting in January 1946, that they should follow the same system as the Philips company.[29] Holst was the director of the Philips "NatLab" (Physics Laboratory), which had been involved in nuclear research before the war. Holst's advice may refer to the company's experience with patents, but in any case it shows how new and unfamiliar secrecy was for most physicists on the Commission. The Commission decided not to speak about its stock of uranium.[30]

By early 1946, the Commission agreed that one should try to build a small "pile" (reactor).[31] Holst advised to consider starting with the smallest possible pile and later see what a large pile could deliver. The Commission agreed that a pile would be commercially justified, as the production of radioactive materials could be put to good use.[32] The Commission members were aware of the strategic value of their uranium and considered trading some for pure graphite, which could be used as a moderator in a pile. A request by Manne Siegbahn in Sweden for several hundred kilograms of uranium in exchange for graphite was denied as such a transaction "would make a bad impression internationally."[33]

Bohr, however, needed some uranium, and it was suggested to "give someone 1 kilogram to take along."[34] So although the uranium was supposed to be a secret, at least Siegbahn in Sweden was aware of it, and Bohr likely was, too. Still, knowledge of its existence remained limited to a small group of scientists and politicians.

Shortly after these discussions, by the summer of 1946, Kramers became chairman of the Scientific and Technical Subcommittee (STS) of the United Nations Atomic Energy Commission (UNAEC) in New York, to explore ways to implement international control of nuclear energy. Besides renewing some of his pre-war contacts, including with the now famous Oppenheimer, he became involved in significant technical discussions. The STS drafted

29. FOM archive 449–378, Notulen van de vergadering van de adviescommissie voor Kernphysica, 25 Jan 1946.

30. Ibid.

31. Notulen van de vergadering van de adviescommissie voor Kernphysica, 25 Jan 1946, NHA, FOM, 449/378.

32. Hoeneveld, *Een vinger in* (ref. 8), 167.

33. Notulen van de vergadering van de adviescommissie voor Kernphysica, 16 Feb 1946, NHA, FOM, 449/378.

34. Notulen van de vergadering van de Commissie voor Atoomphysica, 2 Mar 1946, NHA, FOM, 449/378.

FIGURE 2. Left: Oppenheimer (left) and Kramers in the U.S., around 1930. *Source*: Kramers family private archive. Right: Kramers (with bow tie) behind Dutch Minister Van Kleffens (front, second from left) in the United Nations Atomic Energy Commission, 1946. *Source*: United Nations Dag Hammarskjöld Library.

a technical report that analyzed the different stages in producing nuclear energy, the risks involved, and the possible safeguards this required.[35] This gave him a good understanding of the elements of nuclear engineering, but also of the political challenges in realizing international control. His experience and the network gained from work on the Committee were instrumental to him when the Dutch started their own nuclear project with Norway in 1950.

Clearly, there was no formal policy of secrecy vis-à-vis the Dutch uranium. The Netherlands did not have an Atomic Energy Act that could regulate secrecy until 1963, but came close to adopting such an Act in the late 1940s. In 1948, Kramers and the Dutch ambassador in Washington, Eelco van Kleffens, drafted a Dutch Atomic Energy Act that initially did not contain a secrecy clause. Van Kleffens had been the Dutch Minister of Foreign Affairs from 1939 until 1946, and subsequently became the Dutch ambassador in Washington, DC, in 1947. In 1946, Kramers and Van Kleffens had worked side by side in the UNAEC (see also Fig. 2), and the two men took up the task of drafting an Atomic Energy Act. By late 1948, a discussion developed over whether to include formal secrecy restrictions in the "Kramers-Van Kleffens" draft. At first Kramers did not oppose this but changed his mind after "a highly

35. Richard G. Hewlett and Oscar E. Anderson, *A History of the United States Atomic Energy Commission, Vol. 1, 1939/1946, The New World* (Washington, DC: US Atomic Energy Commission, 1972).

confidential discussion with 'O.', a prominent American."[36] Although the archives do not reveal the identity of "O.," it is highly likely that this was Oppenheimer.[37] Kramers and Oppenheimer had renewed their contact in the UNAEC in 1946. In 1947, they had collaborated closely in the Shelter Island conference on the foundations of quantum mechanics, and again in the 1948 Solvay Conference in Brussels.[38] Kramers signaled his change of mind just days after working with Oppenheimer in Brussels. Kramers had discussed the idea of a secrecy clause with "O.," who had advised strongly against it. As Kramers put it:[39]

> Official legal impositions of secrecy with respect to atomic energy have already now led to the direst consequences in the USA and threaten to end in Russia-like terror situations. The USA is divided on this point, there is a great struggle going on behind the scenes. [. . .] other friendly countries can only help in the right direction, by not following in the footsteps of the USA's extreme "policy of secrecy" but rather by opposing it by a more natural handling.

So Kramers, fed by his discussions with "O.," pushed back against a political request to introduce a formal policy of secrecy. The early Dutch Atomic Energy Act was largely meant to control the significant thorium ores in the Dutch East Indies. As debate over the Act continued, however, the colonies acquired independence by late 1949. This eliminated an important rationale for the law that was never formally adopted. The important point here is how an attempt was made to introduce formal nuclear secrecy by a scientist and a diplomat, working as equals. In 1960, incidentally, the Dutch would be taken by surprise by American security requests concerning their work on uranium enrichment with ultracentrifuges. As Jeroen van Dongen has remarked: "their own [Dutch] lack of a formalized classification system reflected their trust in personal relations and the individual moral judgment of character. In the U.S.,

36. NA, Ministerie van Buitenlandse Zaken 1945–1954, inv.nr. 13099, letter by Kramers, 15 Oct 1948; and "aantekening aan de Secretaris-Generaal" (anonymous and undated).

37. Kramers' letter in ref. 36 contains a suggestion by "O." to develop control of atomic energy in friendly countries through direct interactions between those countries and the AEC. Oppenheimer served on the General Advisory Committee of the AEC at that time.

38. Oppenheimer later deemed the 1947 Shelter Island conference the most successful scientific meeting he ever attended. Kramers made an important contribution to the conference: he was the first to suggest the technique of renormalization in quantum electrodynamics.

39. NA, Ministerie van Buitenlandse Zaken 1945–1954, inv.nr. 13099, letter by Kramers, 15 Oct 1948.

however, a rather more technocratic understanding of how to assess human relations and behavior was prevalent[.]"[40]

Even without a formal secrecy policy, knowledge of the Dutch uranium outside the Netherlands initially remained limited to at most a few individuals in Denmark and Sweden. It did not, however, extend to the other Scandinavian country, Norway, where Gunnar Randers was about to embark on a frantic search for uranium that lasted until 1950.

Gunnar Randers

Gunnar Randers (1914–1992) started his career as an astrophysicist, graduating from the University of Oslo in 1937. He continued his studies in the United States, first at Mount Wilson in California working with Edwin Hubble. In July 1940, Randers transferred to the Yerkes Observatory outside Chicago, where he briefly worked with the astrophysicist Subramanyan Chandrasekhar. He was an exceptional networker; his network included Albert Einstein, with whom he discussed five-dimensional extensions of general relativity.[41,42]

In 1941, Randers moved to the University of Chicago itself, to lecture in astronomy. His office was in the Eckhart Building, where Fermi and his collaborators where working on the "metallurgical project." This was the project designed to produce the first controlled nuclear chain reaction. Even though the project was secret and not accessible to foreign nationals, Randers recalled in 1975 that there was no formal system to prevent discussions on its purely scientific issues.[43] Whereas Randers was interested in nuclear physics, Fermi had an interest in astronomy, and there was close contact between the two groups. Randers joined Fermi and others on swimming trips during the summer in Lake Michigan. He became well acquainted with a number of the nuclear physicists, and became heavily interested in the new nuclear

40. "Introduction," *Cold War Science* (ref. 9), and see, in particular, Chap. 4 by Abel Streefland, "Putting a Lid on the Gas Centrifuge: Classification of the Dutch Ultracentrifuge Project, 1960–1961."

41. In 1941, he published a well-cited article that contains a result that still carries his name; the so-called "Randers metric"; Gunnar Randers, "On an Asymmetrical Metric in the Four-Space of General Relativity," *Physical Review* 59 (1941): 195.

42. On Einstein's work in 5-dimensional theories, see Jeroen van Dongen, *Einstein's Unification* (Cambridge: Cambridge University Press, 2010), chap. 6.

43. Gunnar Randers, *Lysår* (Oslo: Gyldendal Norsk Forlag, 1975), 38.

science. One day in 1942, however, his office was moved out of the Eckhart building while the metallurgical project took over the entire building. As a foreigner, Randers could not participate in the project; yet he remained highly interested and learned what he could from the outside.

A few months before the Chicago reactor went critical, Randers relocated to England to assist in the Allied war effort. While there, Randers was shown Joliot-Curie's 1939 heavy water reactor patent, which he was allowed to study.[44] It was the first time he saw a concrete description of nuclear energy technology. This patent would remain the basis for his thoughts on nuclear energy for the remainder of the war.[45]

In Britain in 1943, Randers briefly worked under John Cockcroft, the British nuclear physicist. Cockcroft would become an essential post-war contact for both Norway and the Netherlands. In the last year of the war, Cockcroft worked on the French-British-Canadian nuclear project in Canada.[46] Under his supervision, the first reactor outside of the United States was built. This heavy water reactor, the Zero Energy Experimental Pile (ZEEP) went critical on September 5, 1945. Cockcroft thereafter returned to Britain to head the British nuclear program at Harwell. He returned with valuable knowledge and hands-on experience, both essential to building Britain's first reactors. Similarly, the French designer of ZEEP, Joliot's pre-war collaborator Lew Kowarski, returned to France bringing essential reactor expertise.

By the end of the war, Randers was in a unique position to consider the construction of a Norwegian reactor. He had become a personal acquaintance both of Fermi, who built the first reactor, and of Cockcroft, who built the first (heavy water) reactor outside the US. Also, he had been able to see and discuss Joliot-Curie's secret heavy water reactor patent. All of this made him realize acutely the strategic value of Norway's heavy water. Although the heavy water plant had been damaged in the war, it was running full-scale again in 1946.[47] Although Norway did not have a need for nuclear power after the war, there was a rationale for pursuing nuclear reactor development. As Randers put it:

44. Ibid., 58–60.

45. Ibid., 59.

46. Margaret Gowing, *Britain and Atomic Energy 1939–1945* (London: Macmillan & Co. Ltd, 1964), 274.

47. Gordon Dean, *Report on the Atom* (London: Eyre & Spottiswoode, 1954), 238.

> It is obvious that any country which does not try to provide facilities for its scientists will lose its best men, and cannot then expect to remain on an equal footing with the countries which accumulate not only their own, but also other nations' top scientists. An undertaking like the Norwegian atomic energy project is therefore not a luxury nor an amusing game for the scientists, but one of the many necessary efforts which a nation today must make to secure its existence in the long run.[48]

In other words, the level of scientific development was ultimately vital to the interests of the state. There was also the question of nuclear weapons. Norway initially kept the option open for a military nuclear program. Because of Randers' wartime experience in Britain, he and about thirty other Norwegian scientists, who did defense related work in Britain during the war, became part of the Norwegian Defense Research Establishment (FFI).[49] Uncertain of how the post-war security environment in Norway would develop, and equally uncertain of how the early international efforts in nuclear control would play out, it intially kept both options on the table, but quickly abandonded possible military dimensions.[50]

Upon his return to Norway, Randers—like Kramers—read the Smyth Report, which he recalled finding intriguing and frustrating at the same time:

> The Smyth Report was not a complete recipe book for building an atomic bomb. It was a recipe where the types of ingredients were described but where the quantities of each ingredient in the desired dish are left out. To find out how much uranium, how highly enriched uranium, how much graphite, graphite of what purity, how much heavy water, what thickness of uranium rods one must have to make a chain reaction, it would be necessary to go through large parts of the same research effort as the "Manhattan Project".[51]

The Smyth Report did make clear that the Manhattan Project involved a tremendous investment in terms of industrial capability and skilled personnel, both scientific and technical. Randers, however, was determined to see if he could avoid having to go "through large parts of the same research effort." He

48. Gunnar Randers, "Planning for Atomic Physics in Norway," *Bulletin of the Atomic Scientists* 6, no. 5 (1950): 142.

49. Astrid Forland, "Norway's nuclear odyssey: from optimistic proponent to nonproliferator," *The Nonproliferation Review* (Winter 1997): 2.

50. Njølstad, *Strålende Forskning* (ref. 7), 26; Roland Wittje, "Nuclear Physics in Norway, 1933–1955," *Physics in Perspective* 9 (2007): 418; Forland, "Norway's nuclear odyssey" (ref. 49), 4–6.

51. Randers, *Lysår* (ref. 43), 94.

FIGURE 3. Gunnar Randers (right) with Dutch Queen Juliana (middle) and Prince Bernhard (left) at an official visit to the Dutch-Norwegian reactor, May 1953. *Source*: Norsk Teknisk Museum, Oslo.

was convinced that his friends in America would help by providing some of the secret missing quantities in the nuclear recipe book.

FISSION NEUTRONS—SECRET REVEALED

Along with knowledge about the required technology and strategic materials, essential knowledge of fundamental physics is required to design a reactor. One important physical quantity on which the size of a design depends is the number of fission neutrons, ν. Together with a few other numbers, such as the fission cross-section, ν determines the size of a critical mass of fissile material, for both reactors and weapons.[52] By early 1946, Randers' calculations had shown him that the required amounts of heavy water and uranium depended sensitively on the number of fission neutrons, ν:

52. The fission cross-section gives the probability that a nucleus will split when hit by a neutron. The critical mass M_c of a weapon depends on the number of neutrons emitted when fission occurs (ν) as $M_c \sim [\sigma_f(\nu - 1 - \alpha)]^{-1.7}$. Here, α is the "branching ratio" σ_r / σ_f, with σ_f the fission cross-section and σ_r the "radiative capture" cross-section.

> If ν were 2.6 for example, one would probably only need a few tons of heavy water. If the number were 2.3, one would need twenty or thirty tons or more and the whole thing would be out of reach.[53]

Clearly, knowledge of this number was crucial to Randers, but it was classified during and after the war, until 1950 (see also Fig. 4).[54,55] Even with the resources of the Manhattan Project, it had been difficult and it had taken a long time, until June 1944, to get an accurate value for ν.[56,57,58] It seemed hopeless for a country as small as Norway, with limited financial and technical means, to determine this value reliably by early 1946. Randers, however, was

One would conclude, in fact, that the excitation in the fragments is considerable, since the value of ν (ν = average number of neutrons per fission) for U^{235}, to take a typical example, is 2.45. This represents more than one neutron per fragment on the average.

Emission of Neutrons in Fission. when the fragment "drops" are somewhat like: ○○ , each fragment possesses considerable excitation energy. This energy is used to a large extent to evaporate neutrons. There is approximately one neutron produced per fragment.

FIGURE 4. Exact number of fission neutrons in Fermi's 1945 then classified Los Alamos lecture notes from the Manhattan Project (above) and the deliberately vague number in his 1949 published University of Chicago course (below). *Source:* 1945 Lecture notes: E. Fermi, "Neutron Physics" lecture notes, Churchill Archives in Cambridge (CHAD-1, Box 13, 4); also published in S. Esposito and O. Pisanti, *Nuclear Physics for Nuclear Reactors—Unpublished Writings by Enrico Fermi*, World Scientific (2010). *Source:* 1949 Course: Enrico Fermi, *Nuclear Physics* (Chicago: University of Chicago Press, 1950).

53. Randers, *Lysår* (ref. 43), 10.

54. National Research Council of Canada, Atomic Energy Project, "Nuclear Data for Low Power Research Reactors," *Canadian Journal of Physics* 29, no. 2 (1951): 203–04, on 203.

55. Under the Manhattan Project, the number would have been accessible to American, British, Canadian, and French collaborating physicists.

56. T. M. Snyder and R. W. Williams, "Number of neutrons per fission for 25 and 49," *Los Alamos Report* LA-102 (30 Jun 1944).

57. $\nu = 2.4355 \pm 0.0023$ for U-235 and $\nu = 2.8836 \pm 0.0047$ for Pu-239; International Nuclear Data Committee, Handbook of Nuclear Data for Safeguards: Database Extensions (Vienna: International Atomic Energy Commission, 2008), Table A-6, https://www-nds.iaea.org/sgnucdat/a6.htm.

58. Ben C. Diven, John H. Manley, and Richard F. Taschek, "Nuclear Data—The Numbers Needed to Design the Bombs", *Los Alamos Science* (Winter/Spring 1983): 116–18.

able to obtain a reliable value in the summer 1946, by talking to his friends in America at precisely the right time.

In July 1946, Randers travelled to the United States together with the Norwegian engineer Odd Dahl. Like Randers, Dahl had worked in the United States before the war, mostly on accelerators.[59] In the eyes of Randers, Dahl was the man who would be able to "realize his [Randers'] own visions and ambitions" concerning Norway's nuclear program.[60] Their trip had two goals: One goal of Dahl's was to make preparations for the construction of a betatron in Bergen.[61] Their other goal was to learn as much as possible from the Manhattan Project and to discuss their own plans for a nuclear reactor. Both goals were meant to improve Norway's scientific stature. One specific wish was to learn the number of fission neutrons, ν. Randers perceived this as a "spying trip," somewhat exceeding the norms of regular scientific exchange. In the opening chapter of his memoir, entitled "Atomic spy in Pasadena," Randers recounts how he and Dahl photographed a report on the roof of their hotel in California. The report described how the number ν was measured using a small homogeneous reactor. It was loaned to them by a "colleague from a physics laboratory."[62]

The fortuitous timing of Randers and Dahl's visit to the United States enabled them to speak to many of the Manhattan Project veterans in a relatively open manner. In fact, many of these veterans argued there was "no secret to be kept."[63] After the war had ended, many atomic scientists—including Hans Bethe, Edward Teller and Robert Christy—had become convinced that wartime secrecy should be abandoned. In their eyes, secrecy had been a necessary evil given the danger of espionage, and they believed they should return to the normal scientific practice of openness.[64] These expectations were echoed at government level as well, such as in a joint statement by the US, UK, and Canada in November 1945:

59. Wittje, "Nuclear Physics in Norway" (ref. 50), 410.

60. According to Njølstad, *Strålende Forskning* (ref. 7), 23.

61. Wittje, "Nuclear Physics in Norway" (ref. 50), 418.

62. Randers, *Lysår* (ref. 43), 9–10.

63. Alex Wellerstein, "A tale of openness and secrecy—The Philadelphia Story," *Physics Today* (May 2012): 48.

64. By late August 1945, the Association of Los Alamos Scientists (ALAS) drafted a document for the Truman administration, signed by 300 scientists. They advocated a policy of openness, emphasizing "that there was no 'secret' about how to build the bomb." From: Monk, *Inside the Centre* (ref. 22), 463–64; Kai Bird and Martin J. Sherwin, *American Prometheus—The triumph and tragedy of J. Robert Oppenheimer* (New York: Vintage Books, 2006), 324.

> Representing as we do, the three countries which possess the knowledge essential to the use of atomic energy, we declare at the outset our willingness, as a first contribution, to proceed with the exchange of fundamental scientific information and the interchange of scientists and scientific literature for peaceful ends with any nation that will fully reciprocate.[65]

In April 1946, declassification became a formal goal when representatives of the United States, Canada, and Britain agreed to adopt common standards based on a Declassification Guide.[66,67] But instead of abandoning secrecy, as many scientists had hoped and expected, in the summer of 1946, the US Congress drafted new legislation that would result in the extremely restrictive Atomic Energy Act, also known as the McMahon Act. It was signed into law on August 1, 1946, and went into effect on January 1, 1947. Under the Atomic Energy Act, sharing nuclear information with another country could be punishable by death, even in peacetime. That was an unprecedented restriction and a sharp reversal from the trilateral pledge to exchange information less than a year before.[68] Just prior to this new legislation, Randers and Dahl were able to profit from this short window of opportunity, when many American scientists anticipated a relaxation of the wartime security measures. Some of them were willing to discuss atomic affairs with their former foreign colleagues whom they trusted, in a relatively open and informal manner.

Randers wrote a detailed travel report for the young Norwegian Defense minister Jens Christian Hauge, who supported the reactor project both politically and financially. Randers noted that the most valuable technical information about the American nuclear power project was gleaned from conversations he had with scientists "who often had a more moderate view on secrecy than the military."[69] Concerning the accelerator project, "wartime security measures were largely abolished," and where they were not, "they were not so strict that personal contacts could not provide

65. "Declaration on Atomic Bomb by President Truman and Prime Ministers Attlee and King, Washington, November 15, 1945," https://carnegieendowment.org/2005/11/01/nonproliferation-turns-60-pub-17664 (accessed 1 Sep 2020).

66. M. Gowing, *Independence and Deterrence, Britain and Atomic Energy, 1945–1952, Volume 2: Policy Execution* (London: Palgrave Macmillan, 1974), 121–22.

67. The first Declassification Conference, however, would not take place until November 1947, in Washington, DC. The second took place in Harwell in September 1948.

68. Krige, "Building the Arsenal" (ref. 6).

69. Gunnar Randers, *Reise til U.S.A. sommeren 1946 for studium av amerikansk atomforskning*, Rapport til Forsvarsministeren, 1946, https://www.ffi.no/no/Rapporter/46-G.s.-F-RH-2.pdf (downloaded Dec 2016).

access."[70] Trust and personal relationships between scientists proved to be more important than "security measures."

In order to make classification work, the government depended on scientists to keep secret information to themselves and not disclose it to outsiders, even if they were or had been close scientific collaborators. Co-construction of classified information by scientists and state officials depended on trust. The latter group found this difficult, as they feared that the scientists would leak. This did happen occasionally, as is evident from the information obtained by Randers and Dahl. Trust among scientists competed with trust between scientists and the state.

Randers had tried and succeeded to get access through personal contacts.[71] The list of universities Randers and Dahl visited is long and substantial.[72] They were able to interview many Manhattan Project veterans who had worked on the uranium and plutonium bombs and on various reactors. In Chicago, Randers visited Leona Marshall Woods, an old acquaintance from his time there in 1942. Woods had been on Fermi's team that built the graphite moderated Chicago Pile-1 (CP-1). In his memoir Randers estimated that this visit alone saved him several hundred thousand kroner before they started their own projects in Norway.[73]

Still more importantly, Randers and Dahl met with Fermi himself and with Walter Zinn in the new Argonne Laboratory, outside of Chicago. Fermi had designed the CP-1 reactor. Zinn had designed the world's first heavy water reactor, CP-3, which went critical on May 15, 1944. Yet more valuable information was obtained through a meeting with Robert Christy, a theorist who had worked on the first enriched uranium reactor, LOPO (for LOw POwer).[74] These meetings provided Randers and Dahl with a good understanding of various types of reactors and a general idea of their requirements. The Manhattan Project veterans understood quite well that, if there were any secrets at all, they were in the engineering achievements and production factories of the Project. Randers and Dahl returned with a clear assessment and "a lot of useful

70. Ibid., 1.

71. Ibid., 2.

72. The list includes Johns Hopkins, Univ. of Virginia, Princeton, Yale, MIT, Harvard, Univ. of Chicago, Argonne Laboratory, Univ. of Wisconsin, Berkeley, and Caltech.

73. Randers, *Lysår* (ref. 43), 49.

74. LOPO had a very small critical mass of only 565 grams, 14% enriched uranyl sulfate, and went critical on May 9, 1944.

data and information": a bomb was not a realistic perspective, but a small heavy water pile did seem feasible.[75]

The classified knowledge that was shared with Randers and Dahl was all of a technical theoretical nature. It was "text-based" information that could be written down. They were carefully kept away, however, from the reactors themselves and the fissile material production facilities of the Manhattan Project. In these facilities a different category of secrets existed, those concerned with non-textual know-how or "tacit knowledge": typical skills and experiences required to operate the processes at these facilities. The number of fission neutrons, in particular, is a typical example of a "discrete, inscribable and transmissible" secret that can literally be transferred on a slip of paper.[76] In 1946, many scientists did not regard this kind of technical information as an important atomic bomb secret, as opposed to the non-textual know-how that existed in the fissile material production facilities.

All in all, Randers was quite content with his visit to the US. As he wrote in his memoir, he was rather confident that "the average number of neutrons from a uranium fission is over 2.4," which he expected would allow Norway to build a reactor with "relatively modest quantities of uranium and heavy water."[77] As the US was able to produce its own heavy water, Norway's heavy water was not important to it. Randers therefore could not use it as bargaining chip to gain further assistance from the US. He did use it as such in his dealings with Britain and France, as I will show next.

THIRD SECRET—REACTOR DESIGN

With the confirmation that Norway could build a reactor with relatively modest means, Randers and Dahl turned their attention to the two main outstanding problems: reactor design and the lack of uranium. While Randers focused largely on the uranium problem, Dahl took up the design challenge. The earliest ideas about heavy water reactors, as we saw, had been developed in France in early 1939: Joliot-Curie and his collaborators had patented a crude heavy water design in May '39. During the war all Allied research on reactors was classified, including this patent, and designs

75. Randers, *Reise til U.S.A* (ref. 69), on 9 and 6.

76. See also Alex Wellerstein, "Knowledge and the Bomb: Nuclear Secrecy in the United States, 1939–2008" (PhD dissertation, Harvard University, 2010), 275.

77. Randers, *Lysår* (ref. 43), 56.

remained classified under a tripartite agreement between England, Canada, and the United States after the war.[78]

Norway's heavy water was particularly useful to any country that wanted to build a reactor with limited means. Whereas a graphite reactor needs at least on the order of ten tons of natural uranium, a heavy water research reactor requires as little as two to three tons.[79] This made it natural for Norway to look for a heavy water design.

The Norwegians gathered a lot of useful information during their "spying trip" in America. Requests to visit the American reactors, however, (including the Hanford production reactors) had all been turned down. By the time the Atomic Energy Act came into effect in January 1947, American help on the reactor side had become completely impossible. Randers and Dahl next turned to the British and the French for help. Both British and French scientists had brought back useful skills and expertise from working on the Canadian ZEEP reactor project. Both countries had started their own reactor programs.

France, when it was shut out of the Anglo-American nuclear monopoly after the war, was not nationally bound to any secrecy agreements, although efforts were made to follow the Anglo-American policy of secrecy.[80] Bertrand Goldschmidt, one of the few French physicists to actually work on the Manhattan Project, recalled the secrecy arrangements the French scientists had been required to agree to, upon leaving the project after the war:

> We who returned to France were in no way formally released from our promises of secrecy [...]. Although Cockcroft had given us, on our departure, a letter authorizing communication of our knowledge to our government, shortly afterwards he asked us to return it saying there had been a misunderstanding [...] Three months later each of us received a new letter from Minister Anderson, informing us that we must continue to respect our pledges of secrecy, from which he could not release us—and from which we were never formally released.[81]

This particular policy of secrecy for the French shows disagreement between the British scientist (Cockcroft) and diplomat (Sir John Anderson). It is similar

78. Alex Wellerstein, "70 Years ago: Vannevar Bush worries about French Patents," *Restricted Data* (blog), 5 Mar 2013, http://blog.nuclearsecrecy.com.

79. The JEEP reactor would eventually run on 2.2 tons of natural uranium fuel. An energy production reactor requires many more tons of uranium.

80. Bertrand Goldschmidt, *The Atomic Complex—A Worldwide Political History of Nuclear Energy* (La Grange Park, IL: The American Nuclear Society, 1982), 250.

81. Ibid., 60.

to the disagreement between Kramers and Van Kleffens. Also in that case, the scientist Kramers, probably advised by Oppenheimer, was more liberal about secrecy than the diplomat Van Kleffens. Goldschmidt, however, came to a slightly different understanding with General Groves, when he raised "the delicate matter of secrecy":

> It was tacitly understood that we could use our knowledge to benefit France by giving information to our research teams, but without publishing it and only to the extent necessary for the progress of our work. That was a reasonable compromise. We applied it during the first years of the CEA, with the agreement of all those in charge and without complaint from any of the interested parties.[82]

The interpretation of "giving information to our research teams" became increasingly less restrictive after these first years: when the Norwegians came asking for information in return for heavy water, French scientists were willing to share information, at first reluctantly but gradually more openly and confidently. In April 1947, Randers was in France and was able to meet all the major players. These included Francis Perrin, scientific director of the newly founded French Atomic Energy Commission (CEA); Pierre Auger; Joliot-Curie, and the minister of atomic affairs, Raoul Dautry. The French indicated willingness to collaborate with Norway, partly because of their interest in heavy water but also out of disappointment of having been excluded from the British-American nuclear pact. A joint program with Norway could put France at the head of an independent nuclear program. Randers also met with Lew Kowarski, the designer of both the Canadian ZEEP and the French heavy water reactor ZOÉ (Zéro de puissance, Oxide d'uranium, Eau lourde). He showed him some of Dahl's latest sketches of the Norwegian reactor design. Randers noted in his memoir: "even though Kowarski is careful to discuss openly, I get a clear impression that our sketches and calculations can't be so very crazy."[83] By this account, Kowarski tacitly approved of the general reactor design.

For Randers, this willingness to discuss the Norwegian plans was a great help.[84] After consulting with the French, Randers and Dahl asked the British for help with uranium and some reactor design issues in exchange for heavy water. They visited Cockcroft on January 28, 1948, who indicated his willingness to assist but noted that formal support depended on American

82. Ibid., 60.
83. Randers, *Lysår* (ref. 43), 131.
84. Ibid., 131.

consent.[85] He further explained that Harwell, where the first reactor was built, might be declassified later in the year. Cockcroft counseled, however, that it would be unwise for Norway to wait for construction details to be released in this way. He agreed with Randers and Dahl that a graphite reflector of 30 cm thickness would be too thin, but had no comment when the figure of 70 cm was proposed.[86] When shown the Norwegian design, he preferred not to comment on the right diameter of the fuel rods, but again accepted Randers and Dahl's own remark that the fuel rods were too thick. By asking specific questions and with Cockcroft giving implicit responses, Dahl and Randers got tacit approval and suggestions for their reactor plans.[87] Cockcroft was not willing to explicitly share information that was still classified by England and America. His response to Randers' and Dahl's questions is similar to Kowarski's tacit acknowledgement. In his report for the British Atomic Energy Council, Cockcroft gave a positive judgment on the proposed design: "It is evident that they have sufficient information to design a low power reactor that would work."[88] Randers inquired informally if it would be possible to trade British uranium oxide for Norwegian heavy water. He also asked if the British were prepared to offer assistance "on some points of design."[89]

Although Cockcroft was willing to help, British scientists were limited in their ability to assist due to Britain's obligations toward America. France, however, had no such limitations and, as mentioned before, had several things to gain from collaborating with Norway. It was agreed between the Norwegian and French Atomic Energy Institutes that a Norwegian scientist could work at the French nuclear reactor site, enabling him to acquire critical know-how or tacit skills needed to master new nuclear technology.[90]

After visiting Cockcroft in England, Randers and Dahl were warmly received once again in Paris. On the 3rd of February, they visited the fuel production facility and were shown purified uranium oxide (UO_2) fuel briquettes. They learned sensitive details such as their size and details on the

85. Referat av konferanser under Randers og Dahl's reise in England, Frankrike og Belgia i Januar, Februar 1948, NNA, Forsvaretsdepartementet, Box H-220/1, no. 23.

86. In this design, a cylindrical layer of graphite is used to reflect neutrons back into the core that would otherwise escape. The moderator is heavy water.

87. Forland, "På leiting" (ref. 7), 11.

88. Cockcroft's report for the Atomic Energy Council, 3 Feb 1948, TNA, AB 6/360.

89. Ibid.

90. Ibid.; Forland, "På leiting" (ref. 7),13.

pressing and sintering procedures.[91] Next, on the 4th and the 5th, they visited the French reactor that was under construction at Fort de Chatillon. They got unlimited access to all its laboratories and noted many of the dimensions of the reactor building, including the dimensions of the reactor, the volume and thickness of the aluminum reactor tank, the number of fuel rods, and the dimensions of the graphite blocks.[92] The conclusions of Randers' report of this visit show great hope and optimism: Norwegian ore—that they hoped to mine domestically—could be purified in France and possibly in England. France could provide reactor graphite. Heavy water, according to Randers, "was a brilliant exchange product against knowledge and materials."[93] Another visit to Paris, in the late summer of 1948, was especially useful. Dahl was now able to thoroughly discuss reactor technology with Kowarski. By the end of the meeting, Kowarski had nothing to add to Dahl's reactor design.[94] Construction work on the Norwegian reactor started in September 1948 in Kjeller.[95] By offering heavy water as barter and making effective use of person-to-person interactions, Randers and Dahl managed to develop a reliable reactor design aided by France's informal guidance. This close cooperation also served both countries' political agendas. France could take the lead in continental nuclear development through its connection with Norway, mitigating its dependence on England and America. Norway could hope to boost its technological status in order to present itself as a modern, technologically advanced nation. At this point only one problem remained for Norway: to actually obtain the required uranium. This is where the Netherlands stepped in.

URANIUM POLITICS—END OF THE DUTCH URANIUM SECRET

Under the post-war Anglo-American monopoly, no uranium was available on the world market in the late 1940s. Randers tried everything he could to obtain the uranium fuel for his reactor. In March 1948, the Norwegian government formally approached the British government through its ambassador with

91. Referat av konferanser (ref. 85).

92. Ibid.

93. Ibid.

94. Ibid., 13.

95. FRUS, *Note by the Secretaries to the Joint Chiefs of Staff on Norwegian Efforts in the Atomic Energy Field*, Appendix B, 2 Sep 1948.

a request for five tons of uranium metal.[96] Although the request was favorably received, the US intervened. The American Joint Chiefs of Staff were particularly worried that the British would provide uranium metal at a (classified) level of purity suited for plutonium production reactors. Consequently, the request was denied.[97] Should Norway be invaded by the USSR, this could "shorten the period of grace during which the United States would be the only nation possessing the atomic bomb."[98] Randers tried repeatedly to get uranium from the British, the French, the Swedish, and the Americans, but each of his requests was denied. Attempts to mine uranium in Norway were unsuccessful. The most promising ores near Evje proved to be too poor.[99]

By early 1950, reactor construction was well underway and Randers was getting increasingly anxious. The French, willing to take the lead in building a Continental nuclear industry, thought they were in an excellent position to negotiate with Norway. Both countries were greatly surprised when suddenly a new option—uranium from the Netherlands—changed the dynamic.

In August 1949, the Soviet Union tested its first atomic bomb and ended the American nuclear weapons monopoly. Dutch scientists, including Kramers, sensed that this was good time to explore nuclear collaboration with other countries. A perfect opportunity to discuss such collaboration arose when the Dutch cyclotron, constructed by the Dutch Institute for Nuclear Research (IKO) was inaugurated in November 1949 in Amsterdam. A special group of "small countries," with which nuclear collaboration appeared feasible, were invited: Belgium, Switzerland, Denmark, Sweden, and Norway.[100] Only the Norwegians were not able to come, so in early 1950 Kramers made a separate trip to Norway.

Before travelling to Scandinavia, Kramers had been in touch with several government officials, including the secretary general of the Dutch Ministry of Foreign Affairs, H. N. Boon. Kramers wanted to discuss to what extent he could share information on the Dutch uranium supply. Boon decided that this would be left to his judgment. Boon did add that if and when something was to be undertaken with the uranium, the United States would have to be

96. Norwegian request for Uranium Metal, 17 Mar 1948, TNA, AB 6/360.

97. FRUS 1948, General, The United Nations, vol. 1, part 2, "Norwegian Efforts in the Atomic Energy Field," 24 Nov 1948.

98. FRUS, *Note by the Secretaries* (ref. 95).

99. Njølstad, *Strålende Forskning* (ref. 7), 57–58.

100. Hoeneveld, *Een vinger in* (ref. 8), 228–34.

informed first.[101] This agreement effectively ended the agreement not to discuss the uranium supply openly and was made in a similar way to the 1939 agreement to keep this quiet. Again a senior scientist and a senior politician made a joint and informal decision concerning the Dutch possession of uranium, this time to open up about it.

On his way to Norway, Kramers made a stop in Copenhagen to see Niels Bohr. In 1945, Bohr had encouraged all countries to start nuclear research, but he had grown more reserved in the following years. He asked Kramers why he did not leave the uranium in the Netherlands.[102] Undeterred, Kramers moved on to Oslo on January 27, 1950. His host Svein Rosseland drove him up to Kjeller the same day. Rosseland assured Kramers that the Norwegian reactor project no longer had a military dimension.[103] Kramers was shown around by Randers and was impressed. The only thing that was still missing from the Norwegian project was uranium. Kramers' revelation that the Dutch had uranium to share came to Randers "like a lifebuoy."[104] When Kramers saw how much work already had been done on the reactor, both men quickly realized that a joint reactor project in Norway with Dutch uranium was the best way forward. The nuclear scientists in both countries were optimistic about this idea to cooperate and quickly managed to draft a cooperation agreement. With that in place, it was time to inform America and England.

On June 4, 1950, Kramers sent a letter to Oppenheimer to ask for his advice on how best to operate in the US. Kramers explained that the idea of the Dutch-Norwegian collaboration started in January with discussions with "uncle Nick and with Oslo people."[105] Oppenheimer had great respect for Bohr, and the implicit suggestion that Bohr approved of the cooperation was probably included to reassure Oppenheimer. Kramers conveniently did not mention Bohr's reservations toward the initiative. As Kramers was recovering from a heart condition, C. J. Bakker, the head of IKO who happened to be travelling to the US, was mandated to talk to the US officials. Kramers wrote to Oppenheimer with the proposed order of business;[106]

101. Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 123; Hoeneveld, *Een vinger in* (ref. 8), 235.

102. Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 123.

103. Goedkoop, *Geschiedenis van* (ref. 14), 40

104. Phrase by van Splunter in "Love at first sight" (ref. 7), 7.

105. "Uncle Nick" is Niels Bohr.

106. Kramers to Oppenheimer, 4 Jun 1950, NHA, H. A. Kramers collection.

> You see, our government approves of our plans but it prefers that we—scientists-technicians—should contact U.S.A. first on a scientific-technical level. Van Kleffens is notified about our steps, that is all. *[. . .] the only thing I would ask you [. . .] is to notify Bakker in case you think we have prepared everything badly and his visit to Washington should be postponed.* Any paternal advice would be welcome too, of course, [. . .].[107]

Obviously Kramers attached great value to Oppenheimer's advice, effectively asking him if the whole business should perhaps be postponed. Oppenheimer thought that first sounding things out on a technical level was a bad idea. He advised Bakker to first talk to the officials at the State Department before talking to the US AEC. The Dutch Ambassador to the USA, Van Kleffens, gave the same advice. On June 20, Bakker wrote Kramers from Berkeley to brief him on his Washington visit. Bakker had first met with State Department officials, including John D. Hickerson (Assistant Secretary for United Affairs of the State Department), and informed them of the Dutch-Norwegian plans. Bakker noted that Oppenheimer's advice to first talk to the State Department had been "very wise." Hickerson asked if he was the first to be informed officially on this matter, and Bakker could reassure him on this point. Although this was a minor contribution on Oppenheimer's behalf, his advice illustrates that the government's role in nuclear policy was more significant in the United States than in the Netherlands, where this was still largely left to the scientists. Hickerson indicated that he was favorably inclined toward the joint project: "if any work should be started with hexa in Western Europe, the USA would trust it to these countries first."[108]

The next day, Bakker met with the AEC, including Henry DeWolf Smyth and Malcolm Henderson, deputy to Walter Colby (Director of Intelligence at the AEC). Again, he gave a survey of the plans. Both Smyth and Henderson indicated that security would not be a problem, as they thought that it was almost certain that very soon all data about small piles (up to 1 MW) would be declassified. "Therefore their opinion was that security would be completely our problem, the USA being scarcely interested."[109] They were also positive about Dutch-Norwegian collaboration:

107. Kramers to Oppenheimer, 4 Jun 1950, NHA, H. A. Kramers collection (emphasis added).

108. Bakker to Kramers, 20 Jun 1950, NHA, H. A. Kramers collection

109. Ibid.

> If European countries must co-operate in this field, and it appears that they feel they must, a Norwegian-Netherlands combination is perhaps the best of the lot from our point of view. We feel we can neither give any special assistance to, nor seek to oppose, these modest developments.[110]

Another reason for the AEC's positive attitude transpired when Smyth mentioned Sweden. In 1948 and 1949, Randers had explored nuclear collaboration with Sweden.[111] Contrary to Norway, Sweden had promising uranium ores but lacked heavy water. Collaboration seemed logical. In 1949, however, when the North Atlantic Treaty Organization was formed, the Netherlands and Norway were among the twelve countries to agree upon a common security policy. Sweden had not signed up because it chose to continue its policy of neutrality but thereby made itself more vulnerable to a potential Soviet invasion.[112] Precisely this circumstance had made the Americans reject a Norwegian request for uranium in 1948.[113] Smyth thought it was "a logical development" that cooperation with Sweden was off the table. At the same time, fear of the effects of leaks to Russia had diminished after the Soviet test the previous summer. Collaboration with France was discouraged.[114] The US was quite willing to share all declassified information. Bakker's conclusion for Kramers was that they could go ahead and should not expect to meet any difficulties from the Americans.[115,116]

In England, Kramers first informed Cockcroft about the Dutch-Norwegian plans by letter, dated July 5. Kramers revealed the existence of the Dutch uranium that was acquired before the war "due to the foresight of W. J. de Haas," and hidden from the Germans during the war:

110. Van Splunter, *Kernsplijting en diplomatie* (ref. 7), 127.

111. Forland, "På leiting" (ref. 7), 17–20.

112. Ronald Doel, "Scientists, Secrecy and Scientific Intelligence," in Van Dongen, ed., *Cold War Science* (ref. 9), 20.

113. FRUS, *Note by the Secretaries* (ref. 95).

114. Even though the communist Joliot-Curie had just been relieved of his post in April 1950, an advanced and unchecked French nuclear program was still not in America's interest.

115. Bakker to Kramers, 20 Jun 1950, NHA, H. A. Kramers collection.

116. Despite Dutch concerns about surprising the US with its uranium supply, the fact that "the Dutch have a small quantity of uranium which they obtained from Belgium before the war" (no further details) was communicated to the American President in 1949; "A Report to the President by Special Committee of NSC on Atomic Energy Policy with Respect to the U.K. and Canada," 2 Mar 1949, 23–24, National Security Archive Washington, Nuclear Non-Proliferation Unpublished Collection, Box 7.

> From 1945 on we hesitated to dive into the considerable cost of buying the necessary amount of moderator and building a reactor, but this collaboration with Norway will meet the deficit in both countries. [. . .] now we will be glad soon to play with neutrons ourselves. If you have still any fatherly advice on the business, please let me know.[117]

After conferring with their respective Foreign Offices, a meeting was held in London on July 25th between Kramers and Cockcroft, the Dutch ambassador Baron Gevers and Sir Roger Makins, Deputy Under-Secretary of State at the British Foreign Office. Cockcroft expressed his skepticism that the reactor would be powerful enough to do useful research. He felt that the power level should be at least 100 kW, which Kramers could confirm: it was designed for between 100 and 200 kW. It was agreed that Kramers "should keep in close informal contact with Sir John Cockcroft on all technical and related matters."[118]

FOURTH SECRET—URANIUM METAL

The initial idea of Dahl and Randers had been to follow the French example on fuel production. The process consists of two steps: first, the raw ore must be purified in order to get rid of neutron absorbing impurities, then the purified ore must be converted into fuel elements. There are two options here: fuel made from purified uranium oxide (the French choice), or fuel made from purified uranium metal (the British choice). The higher density of metal is preferable, but metal is more difficult to make than oxide. The French pressed their uranium oxide into high density "briquettes." Dahl's reactor design reckoned accordingly with thick oxide fuel elements. This worked well in the French zero-power[119] ZOÉ reactor, but it was not immediately obvious that this would work equally well at higher reactor power.

Now Cockcroft suggested that the use of oxide would not be possible at the desired power level of 100 kW, let alone the eventual, hoped-for power of 450 kW. His calculations showed a limit of around 10 kW.[120] Kramers and

117. Kramers to Cockcroft, 5 Jul 1950, TNA, AB 6/512.

118. Roger Makins, Record of Conversation, 25 Jul 1950, TNA, AB 6/512.

119. A "zero-power reactor" maintains a nuclear chain reaction at a very low thermal power level. It requires little or no cooling capacity. Because of a low neutron flux low, it is less interesting for doing experiments.

120. Njølstad, *Strålende Forskning* (ref. 7), 76.

Cockcroft concluded that the temperature in the oxide at 100 kW would go up to 1500°C, thereby destroying the oxide.[121] They had miscalculated by a factor of 1000, however, possibly mistaking calories for kilocalories. Randers and Dahl had attempted to get data on the thermal conductivity of uranium oxide abroad but had failed.[122] Randers doubted the reliability of the calculation but did not have the hard data to prove it wrong.

The discussion on the preferred fuel had been compartmentalized because of its classified nature. One can only speculate if this error, which resulted in a different fuel choice, would not have been recognized earlier in a more open exchange involving other critical minds.[123] Alternatively, if Randers and Kramers had taken more time to sort this out, they might have come to a different conclusion. But particularly Randers was in a hurry to get the reactor critical as soon as possible. The consequence of all this, however, was that uranium metal, which had a proven performance at higher reactor power, became the preferred fuel, instead of uranium oxide.

The British had developed their own process for uranium ore purification and subsequent production of metal at great cost. The process was classified.[124] On August 8, 1950, Kramers wrote to Cockcroft and asked for his help in acquiring British uranium metal.[125] Cockcroft indicated that this would depend upon the approval of the declassification proposals made at the last declassification conference. He asked Kramers to submit an inquiry to the British Foreign Office "whether they would be able to turn your uranium oxide into metal."[126] When the British mentioned the proposed transaction to the Americans, the latter requested a formal consultation. The Americans regarded the British purification of uranium for another country as "constituting a transaction which under existing Anglo-American arrangements required prior consulting with them."[127] Cockcroft informed Kramers that he had some trouble getting American consent for the agreement.[128] In his request for American consent, the British ambassador to Washington, F. W. Marten, insisted that "there is, of course, no intent of giving the Dutch or

121. Goedkoop, *Geschiedenis van* (ref. 14) 46.
122. Njølstad, *Strålende Forskning* (ref. 7), 76–77.
123. Randers did point out that he saw no problems in using oxide.
124. Gowing, *Independence and Deterrence* (ref. 66), 376.
125. Kramers to Cockcroft, 8 Aug 1950, TNA, AB6/512.
126. Cockcroft to Kramers, 11 Aug 1950, TNA, AB6/512.
127. Makins to Nichols, 23 Nov 1950, TNA, AB 6/512.
128. Minutes of the Joint Commission, 23 Feb 1951, NHA.

Norwegians any information about the process used in purifying uranium oxide."[129] Again, the production process was regarded as more sensitive than factual, text-based information such as the thickness of the fuel rods, which was now readily discussed.

It turned out that the British had a huge supply of metal rods that had been rejected for use in their plutonium production reactors. In November and December 1950, a consensus developed that it would be easiest if the Dutch unpurified uranium oxide would simply be exchanged for the rejected British fuel rods.[130] The rods could still be used in the low-power reactor in Kjeller. A major issue, however, was the chemical purity of the metal rods. In order to operate at the high power level needed to produce an appreciable amount of plutonium, the purity had to be higher than required for operation in a low-power reactor. The required purity level of the metal elements was classified, but by providing the metal fuel rods in exchange for raw oxide, information about the purity level would be shared with the Dutch. After much fretting and a failed proposal by Cockcroft to degrade the purity, the trade went ahead anyway, in the expectation that recent declassification proposals in this area would be accepted soon.[131]

The uranium metal production process was classified "top secret" and only declassified in 1956.[132] Randers preferred to have a completely open international nuclear collaboration, but the British were not willing to share this secret. He realized that the only way to get reliable fuel elements quickly was to accept the British position. Since the reactor was designed for uranium oxide fuel elements that were a lot thicker than the British metal elements, a special solution had to be implemented. Based on calculations by the British, it was determined that two metal bars could jointly be put in place in the fuel channel designed for the oxide bars (see Fig. 5).

By this arrangement, the British created dependency and thus a form of control over the Dutch-Norwegian program. British national interests prevented the sharing of the uranium metallurgy secret even as it enabled the Dutch-Norwegian collaboration to circumvent it by trading raw oxide for the finished product. At the same time, French involvement was frustrated, which

129. Marten to Gordon Arneson, 25 Oct 1950, TNA, AB6/512.

130. Cockcroft to Hinton, 8 Nov 1950, TNA, AB6/512; Cockcroft to Kramers, 4 Dec 1950, TNA, AB6/512.

131. Cockcroft to Peirson, 12 Dec 1950, and Peirson to Cockcroft, 16 Dec 1950, TNA, AB 6/512; Cockcroft to Peirson, 12 Dec 1950, TNA 6/512.

132. Peter Galison, "Removing Knowledge," *Critical Inquiry* 31 (2004): 234.

FIGURE 5. British uranium metal fuel rods, welded in pairs to fit the Norwegian reactor design. *Source*: Author picture from IFE, Kjeller, Norway.

prevented the French from taking the lead in a nascent European nuclear industry. This was especially disappointing for the French physicists. By early 1951, 50 tons of French reflector graphite had arrived at Kjeller, in exchange for heavy water.[133] It did not result in the desired Franco-Norwegian nuclear collaboration.

The British Foreign Office and the Dutch authorities agreed that there should be no public announcement of British assistance in terms of the oxide-for-metal exchange. Randers supplied a code name for the uranium metal: "Tungsten Alloy."[134] On June 14, 1951, the Tungsten Alloy was finally shipped to Oslo.[135] This put the last piece of the puzzle into place, and on July 30, the Dutch-Norwegian reactor went critical for the first time. It was baptized JEEP: the Joint Establishment Experimental Pile. The name recognized the bilateral ("joint") cooperation that was behind it. At the same time, it was an implicit reference to Kowarski's ZEEP (Zero Energy Experimental Pile) in Canada and the British GLEEP (Graphite Low Energy Experimental Pile), to which it owed much. Without the help of the British and the French, JEEP could never have been built and operated as quickly as it had been.

133. M. C. Parsons, *Atomic Energy Research in Norway*, 28 Feb 1951, US National Archives, RG 84, Oslo Embassy, Gen. Class. Files 1945–1951, Box 22, Entry 3053.

134. Arnold to Clarke, 12 Mar 1951, TNA, AB6/512.

135. Shipping order, signed by J. H. Keane, 14 Jun 1951, TNA, AB6/512.

JEEP was truly a transnational achievement. It used Norwegian heavy water with British uranium fuel elements, traded against Dutch uranium oxide, and a graphite reflector provided by France. Furthermore, the JEEP design was largely inspired by the French reactor design. The British computationally verified the final adapted fuel configuration. It was the result of an international collaboration, albeit one that was negotiated and shaped through power politics and changing geopolitical alliances.

CONCLUSION

What can the history of the Dutch-Norwegian reactor tell us about the circulation of knowledge or the (im)mobility of information? How did these small European powers succeed in creating the first reactor outside of the Great Powers? Scientists in the Netherlands and Norway used their networks, which were at the same time scientific, diplomatic, and personal, to enter into nuclear territory that was initially off-limits. The four "secrets" I have presented here bring out three key factors that allowed or impeded the movement of nuclear knowledge: the availability of strategic materials, individual interactions between scientists, and national interests of states. In each of the four cases at least one of these factors was instrumental in gaining access to classified or otherwise restricted information or technology.

The decision to acquire uranium covertly in the Netherlands in 1939 was taken jointly by a scientist, De Haas, and the Prime Minister, Colijn. By keeping its supply secret after the war, the Netherlands retained the option to chart an independent course with respect to America and England as the early Cold War unfolded. In 1947 and 1948, Kramers and the Dutch ambassador to the United States, Van Kleffens, together drafted a Dutch Atomic Energy Act. They disagreed on the introduction of formal nuclear secrecy provisions: Kramers opposed it, and was probably advised to do so by Robert Oppenheimer. Such disagreements suggest that scientists and state officials both shared the need for secrecy, yet weighed their interests and principles differently. In 1950, the decision to open up about the Dutch uranium was again jointly taken by a scientist, Kramers, and a diplomat, Boon. The United States then had to be informed about the wish to collaborate with Norway. Kramers again sought and obtained Oppenheimer's advice in this matter. The way to handle this potentially sensitive move was coordinated by Kramers, Oppenheimer, and Van Kleffens. The US finally gave its support to the Dutch-Norwegian "modest developments."

The idea to keep the number of fission neutrons secret was first suggested by physicists early in 1939. It was initially unsuccessful, as were early attempts to establish a reliable number. Formal and more successful secrecy policies were adopted during the war in England and the United States, and continued after the war in the 1946 McMahon Act. Nevertheless, Randers and Dahl obtained the number through personal interactions with scientist friends just prior to the adoption of this new and highly restrictive law. Although the state stipulates in principle when and how knowledge circulation can take place, Randers found that scientists often "had more moderate views regarding secrecy than the military." The number was only declassified officially in 1950.

The successful construction of the Dutch-Norwegian reactor might simply seem due to the fact that these countries possessed uranium and heavy water, two essential materials to build such a small reactor. Although important, the wider significance of these materials has not been sufficiently recognized. They were highly relevant politically and helped to secure other critical materials. More importantly, as I have argued here, they helped to secure essential skills and knowledge. As Randers put it, the Norwegian heavy water was "a brilliant exchange product against knowledge and materials." Indeed it provided him with 50 tons of pure graphite for the neutron reflector and all-important access to the technical details of the French reactor program, including its reactor design. On the Dutch side, uranium produced access to the Norwegian program with its established reactor design, the knowledge the Norwegians had acquired as well as their materials. It also offered political leverage vis-à-vis the British and the Americans. As it turned out, not a single gram of Dutch uranium went directly into the JEEP reactor: it was exchanged for ready-made uranium metal fuel rods supplied by Britain.

Although the UK was willing to trade fuel against unpurified oxide by late 1950, it had to lobby the Americans for their consent. The British were unwilling to share any of the classified details of either the purification procedure or the metallurgy process with the Dutch-Norwegian collaboration. The alternative, to provide ready-made metallic fuel rods, had two important political consequences: First, it created a dependence of Norway and the Netherlands on the British program, providing the UK with a measure of control. Second, the French, who had invested significantly in the Norwegian program in their effort to take the lead in a European nuclear program, were effectively sidelined. Partly because of Joliot-Curie's earlier communist sympathies, any collaboration with the French nuclear program was suspect and strongly discouraged by the US and the UK.

America's post-war hegemonic position was initially expressed by an attitude of monopolizing rather than sharing nuclear knowledge. However, "by 1947 it was evident to senior policymakers in the U.S. administration that they could not leave continental Western Europe to its fate."[136] Smaller countries in Europe responded to this by organizing their own research organizations in anticipation of a more open future with the US. By establishing their joint reactor project, both the Netherlands and Norway were effectively lined up to co-construct American hegemony in nuclear physics. In the meantime, British scientists and politicians came to support the joint reactor project, thereby strengthening their own nuclear position in Europe.

In the timeframe of this history, there were three years in which secrecy policies were particularly in flux: 1939, 1946, and 1950. In these years new and sometimes narrow windows of opportunity opened up that enabled specific nuclear developments in the Netherlands and Norway. In 1939, the possibility of a nuclear chain reaction first emerged, and a discussion of what secrecy measures were appropriate against the background of the approaching war ensued. The Dutch benefitted from a brief opportunity for open scientific exchange, which enabled an early and covert acquisition of uranium. In 1946, a new secrecy regime was realized in America through the McMahon Act. Just before it was adopted, Randers and Dahl managed to collect valuable nuclear information through their personal contacts. That information confirmed that a small Norwegian reactor would be feasible and helped them to start a program. Finally, in 1950, new secrecy standards were set after the Soviet Union had exploded their bomb and when it became evident how much information had leaked from the Manhattan Project through spying. This new situation finally enabled British scientists and diplomats to assist the Dutch-Norwegian collaboration. The successful completion of the joint reactor in 1951 emphasizes material, interpersonal, and political dimensions as important conditions for the circulation of knowledge.

ACKNOWLEDGEMENTS

I thank Jeroen van Dongen for his time and suggestions that helped to shape this article. Friso Hoeneveld, Ad Maas, and Eline van den Heuvel provided valuable feedback. I also thank Abel Streefland, Paul Josephson, and Alex Wellerstein for critical

136. Krige, *American Hegemony* (ref. 20), 254.

comments. I am grateful to Cees Wiebes for his suggestions and access to his personal archives. In Norway, I thank Viktor Wikstrøm and Pål Nygaard, then at the IFE in Kjeller, for showing me around the old JEEP reactor building and providing access to archival materials. I also thank Olav Njølstad, of the Norwegian Nobel Institute in Oslo, for early input and useful leads. Finally, I thank Martine Kramers and Koos Kuiper, youngest daughter and grandson, respectively, of Hendrik Kramers, for providing me with access to their family archives.