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The Road to Self-Reliance of the First French Atomic Bomb

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Abstract: After World War II, the choice of the plutonium bomb as the technology roadmap for the first French atomic bomb was not a military issue, but rather one guided by civilian nuclear technology policy. After consideration of the amount of uranium to be mined, technical reserves, and the financial situation, the civilian nuclear energy project of the *Commissariat à l'Énergie Atomique* (CEA) was based on plutonium and natural uranium as the fissile materials, which indirectly provided enough plutonium for the future development of a nuclear weapon. When the Fourth Republic decided to develop the atomic bomb, a "Common Core" was established with the CEA, a public institution, as the lead, assisted by the military. Faced by the US embargo of nuclear weapons technology, the co-existence of civilian and military branches and their collaboration to some degree in the CEA not only made it a civilian-military complex, but also facilitated breakthroughs in the core technologies of implosion, the plutonium core, the tamper, and the neutron source. The success of the first French nuclear weapons test on February 13, 1960, announced that France was on its way to becoming self-reliant in the military use of nuclear science.

Keywords: self-reliance, first French atomic bomb, *Commissariat à l'Énergie Atomique* (CEA), Big Science Project

摘　要：第二次世界大战之后，选择钚弹作为法国第一颗原子弹的技术路线，并不是一个军事问题，而是选择民用技术的“附属品”。在考虑了铀的开采量、技术储备和财政状况后，法国原子能委员会的民用核能项目是以钚和天然铀作为裂变材料展开的。这间接为未来发展核武器提供了足够的钚。当第四共和国决定发展原子弹时，以法国原子能委员会这个公共机构为主导，在军方的协助下，建立了一个“共同核心”。面对美国对

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核武器技术的禁运，法国原子能委员会中民用和军用部门的共同存在与一定程度的合作不仅让其成为一种“民-军复合体”，而且在内爆、钚芯、填塞物、中子源等核心技术上取得了突破。1960 年 2 月 13 日，法国首次核武器试验的成功，宣告了法国在核科学的军事用途上走向了自力更生的道路。
关键词：自力更生，法国第一颗原子弹，法国原子能委员会，大科学工程

1 Introduction

The development of France’s nuclear weapons constitutes a major topic in the international history of the Cold War. There has already been much research internationally about the development of the first French atomic bomb. However, their focus has largely been on the surrounding political and diplomatic history. In 1987, Western academics launched the Nuclear History Program (NHP), a transnational project that brought together nearly 200 scholars from the United States, the United Kingdom, Germany, and France. The goal of the project has been to collect relevant archives, focusing on the political aspects of nuclear weapons and their role in the evolution of relations between Europe, the United States, and the Soviet Union. The French sub-group, *Groupe d’études françaises d’histoire de l’armement nucléaire* (GREPHAN), has been led by the *Institut d’histoire des relations internationales contemporaines* (IHRIC), under the direction of the famous scholar of the history of international relations—Maurice Vaïsse. The output of this sub-group includes, for example, Vaïsse (1992), which specifically addressed political considerations in the development of nuclear weapons in France. In his doctoral dissertation, published in 1997, his PhD student, Mongin (1997) revealed the causes and consequences of policies related to French nuclear weapons development, and that R&D on the first atomic bomb had been progressing since the Fourth Republic, but secretly. Mongin and Duval (1993) also extended the period under discussion considerably to the building of the nuclear deterrent during the Fifth Republic. They argued that there was a remarkable continuity in the policies surrounding nuclear weapons by each government, that is to bring France into the ranks of the great powers and for the country to maintain its status and continue to have an impact on world affairs. These goals led to a consensus around the French nuclear deterrent at the national level. Duval (1989), as a witness to the development of nuclear weapons, also wrote an article dedicated to the origins of French nuclear deterrence doctrine. Le Baut’s research (1989; 1996) concerned the political influence of French nuclear weapons tests. Recently, criticisms of the works of GREPHAN have emerged in the international academic community. For example, Cooper’s (2022) doctoral dissertation argues that research conducted by GREPHAN served as a defense of the French official line, making their relevant assertions biased at times. Pelopidas and Philippe’s article (2021) has shown that under de Gaulle, French nuclear strategy was more political than military, and that France failed to establish an effective nuclear strike capability. In addition to the criticisms of GREPHAN, Adamson's doctoral dissertation (2005) provides an in-depth analysis of the organizational structure of the CEA, including the organization of the development of nuclear weapon from the perspective of institutional history. Therefore, many issues remain to be discussed, in particular, an analysis from the perspective of the history of science and technology.

After the establishment of diplomatic relations between France and China in 1964, the nuclear weapons issue became an important topic in high-level exchanges between the two countries. The leaders of both countries considered self-reliance and independent R&D of nuclear weapons to be common features of the approaches of both countries to this issue, a factor in sustaining Sino-French relations.[1] For France and China, developing the atomic bomb was not about invention, but rather about the solution to developing a certain technology from scratch in a particular context, reflecting different characteristics to the attitudes of the United States, Soviet Union, and United Kingdom. In China's official expression, China's atomic bomb became an important representation of self-reliance and self-improvement. So, from the perspective of the history of science and technology, is this representation from a political standpoint close to the truth in France? This study approaches the first French atomic bomb as a subject to be examined from this perspective. It will focus on the scientific and technical factors involved in the exploration for uranium, in the choice of the technology roadmap adopted for the atomic bomb, the technical problems to be solved in its development, and the siting and observation of the first nuclear weapon test.

2 Exploration for uranium

The *Commissariat à l'Énergie Atomique* (CEA) was established on October 18, 1945 by the *Gouvernement provisoire de la République française* (GPRF). The CEA was the first public institution in the world to conduct nuclear research.[2] It reflected the institutional importance attached by the French to this discipline. Although France did not have the same number of world-renowned nuclear scientists as the United States, it still had many top-notch researchers in this field. The CEA brought them together in the hope that all possible measures be taken to enable the country to benefit from its

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1 We can find this expressed in many documents, for example: Archives de Ministère des Affaires Etrangères (AMAE), 119QO/506, Réponses à la proposition chinoise de désarmement nucléaire, le 10 décembre 1964; AMAE, 119QO/754, positions de la Chine et de la France à l'égard du désarmement; AMAE, 119QO/753, Entretien du Président Mao Tse-Tung avec M. Bettencourt, le 16 juillet 1970; AMAE, 119QO/761, Note, Objectif de voyage, le 20 juin 1972, etc.

2 Major Paul O. Langguth to Lt. Col. Richard H. Free. Atomic Energy Research in France, August 29, 1946. Top Secret. NARA, RG 77, Entry 22, Box 173.

development. In the United States, a corresponding institution was established only in 1947. Frédéric Joliot-Curie was appointed as the first High Commissioner of the CEA. His research group had held the world's first patent on the use of nuclear explosives in 1939. However, in 1940, he stressed that the most important application of nuclear science would be to produce large amounts of energy through a combination of natural uranium and heavy water in order to save coal and oil. Their experiments were unfortunately interrupted by the German invasion of France in May 1940 (Pinault 2000, 145, 173, 174). His work in the CEA can be seen as a continuation of his pre-war research. Fissile material is critical for both the peaceful and military uses of nuclear energy research. However, France's access to fissile material after World War II was cut off by the Americans. In fact, during the Manhattan Project, the British and Canadians had held a privileged status as partners of the US, while the French had been excluded. The Quebec Agreement, concluded in August 1943, had provided for close consultation between Canada, Britain, and the United States, and Washington was determined to pursue a policy of protecting nuclear secrets in order to prevent the spread of new weapons.[3] On October 3, 1945, President Truman stated that prompt action must be taken to prevent the misuse of nuclear research and to control the necessary raw materials, whether for peaceful or warlike purposes, and to this end, the United States could acquire, by purchase or requisition, any mineral or other material from which atomic energy could be derived.[4] After 1945, the natural uranium produced by the *Union minière du Haut-Katanga*, which cooperated with the Joliot-Curie group in the 1930s, was fully owned by the United States. Thus, subsequently the only way the CEA could secure a supply of raw materials was through conducting mining research (Mongin 1997, 52). At the time, little was known about uranium deposits in French territories, and the literature that was available was not only brief, but often not very credible, and was soon considered to be of no real geological or metallogenic significance (Lenoble 1955). US intelligence believed that France had no large uranium or thorium resources, and no external supplies, making it impossible for France to launch an atomic energy research program any time soon.[5]

The CEA recognized the need to establish as soon as possible new methods of prospecting and research that could be readily modified based on results and that would allow for a general inventory of France's uranium resources. On December 5,

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3 Detailed studies on this issue can be found in Skogmar (1993). It critically examines the triangular relationship between the United States, Britain, and France in the nuclear field from 1939 to 1950, and the lessons that could be drawn for inter-Union and European cooperation in defense and security matters.

4 Harry S. Truman. Special Message to the Congress on Atomic Energy, October 3, 1945. Harry S. Truman Library.

5 Henry Lowenhaupt, Subject: Review of the French Atomic Energy Development, July 25, 1946. Top Secret. National Archives and Records Administration (NARA), RG 77, Entry 22, Box 173.

1945, the *Laboratoire de Minéralogie* of the *Muséum National d'Histoire Naturelle* in Paris organized the first seminar on uranium for professional prospectors, directed by the chemist and geologist Professor Jean Orcel, a comrade of Joliot-Curie in the Resistance during World War II. The first group of professionals trained consisted of fifty people.[6] The seminar was later moved to La Crouzille, about 20 km from Limoges. France subsequently established the *École de Prospection pour l'Uranium* in Razès (Touret 2005). Through these activities a preliminary plan was developed: firstly, to define a guide to their geological work - the French targeted geographic areas based on the mechanisms of uranium formation generally accepted by the academic community at that time. Secondly, their tactics were defined to accommodate to the organization of each phase of the study, the distribution of teams, and the roles of the various types of personnel. Finally, the characteristics of the equipment to be used in each phase were determined.[7]

In terms of geological understanding, the French made use of principles of prospecting that suited the context of their country: first, strata generally favorable for finding uranium were composed of granites of the Hercynian or sepiolite varieties. Such geological structures are concentrated in the central plateau of south-central France. All the proven uranium veins or seams were located near the main tectonic faults affecting the granitic massif, either in the massif or in metamorphic rocks on its margins. Second, important uranium deposits in France were associated with calcareous gangue. The gangue of the deposits essentially contained calcium and fluorite, which tended to resist alteration and destruction, and the most common mineral that accompanied uranium ore was pyrite. There was, however, no definitive formula that could be applied for uranium ore surveys located in sedimentary rocks as the situation in such cases was more complex and varied compared to granites. In the case of sedimentary deposits with coeval mineralization, the French could only determine the presence of mineable zones by measuring radioactivity. In the case of shales or sandstones with hydrothermal mineralization, priority was given to finding uranium deposits in organic-rich shales, but this involved stratigraphic, lithologic, and tectonic studies and would require more complex exploration projects (ibid). In addition, geochemical and geophysical knowledge was applied to exploration. In geochemistry, water and alluvial prospecting is performed simultaneously with soil prospecting. Wide grid hydro-geochemistry was used to identify favorable areas. Soil prospecting, on the other hand, was dedicated to the detailed study of the discovered leads (Coulomb, Goldstein, and Le Mercier 1958). For geophysics, the French used the resistivity method to detect areas with leads to provide structural information to

6 Lt. Col. Edgar P. Dean, Office of the Military Attache, American Embassy London, to Col. L.E. Seeman, Subject: Review of the French Atomic Energy Development, November 18, 1946. Top Secret. NARA, RG 77, Entry 22, Box 173.

7 Rapport de CEA, no. 401, le 1er juin 1955.

geologists, a method that proved fruitful in the study of homogeneous rocks with simple structures. However, knowledge of these disciplines was not available to all prospectors and required special instrumentation, thus requiring the formation of special geochemical and geophysical teams for the task.[8]

At the technical level, the French recognized the importance of surveying and exploration equipment. The CEA saw the need to overcome the high costs and difficulties of equipment maintenance, seeking to turn them into a tool of daily use like the hammer, and general exploration increasingly turned to the use of instruments (ibid). Radiation measurements were in some cases more accurate than geological measurements. The CEA considered it necessary to diversify and adapt the equipment to the objectives, preferably using lighter instruments as well as multi-tube Geiger counters, choosing the S.R.A.T 3-tube counter or the G.M.T 14. With this equipment, the French invented the "25-meter grid detail prospecting" method, which involved a prospector and two or three workers. The prospector was equipped with a Geiger counter and spread his team over the territory to be explored to cover each area one after another. The workers were equipped with A.V.P or lighter equipment and walked in line 25 meters apart, taking a reading every 5 meters, or every 6 steps. When 100 meters had been covered, or a hectare, the person in charge would note on a map the amount of radiation read by all counters on the area traversed. Using this method they were able to survey up to 20 hectares per day. The Vilbert-Lourmat scintillator radiometer was adopted later. Scintillator radiometers were usually carried on a vehicles during exploration. This was 5–6 times faster and could explore a larger area, but could not be used in forested and mountainous areas.[9] For further prospecting, in the absence of drilling machines in the early period, prospectors used to set small shafts up to 10 and 12 meters deep, but they were often deceived by the weathering of the granite at these levels, and this method was discontinued after the mass adoption of drilling machines.[10]

Thanks to the efforts of the CEA, three mining departments were established: at La Crouzille in May 1948, at Grury in March 1949, and at Lachaux in June 1949. On November 25, 1948, the French confirmed the existence of an important uranium vein at La Crouzille. It was later named Henriette after the wife of Marcel Roubault, the CEA head of prospecting and exploitation. By September 1952, the total production of uranium in France reached 60 tons (Blanc 2008). By 1955, ten years after the commencement of exploration, the CEA proudly announced that France had become the most important uranium producer in Western Europe.[11]

8 Rapport de CEA, no. 1247, le mars 1959.
9 Rapport de CEA, no. 401, le 1er juin 1955; Rapport de CEA, no. 1247, le mars 1959.
10 Rapport de CEA, no. 1247, le mars 1959.
11 Rapport de CEA, no. 401, le 1er juin 1955.

3 The choice of the technology roadmap

It was civilian technology, not military factors, that influenced the choice of the technology roadmap for the first French atomic bomb.

Joliot-Curie was deeply influenced by the concept of the social responsibility of scientists proposed by Paul Langevin and other scholars. He believed that scientists have the ability and obligation to play a special role in the quest for peace and human well-being. Thus, although there were military representatives in the CEA, with the rise of the international intellectual movement to ban nuclear weapons, Joliot-Curie joined the ranks of those who opposed the manufacture of atomic bombs and actively promoted the peaceful use of atomic energy (Pinault 2000, 139–141, 511–528). Under his leadership, France broke the American embargo and from 1948 became self-sufficient in natural uranium (Blanc 2008). In the same year, the first French nuclear reactor ZOE (*zéro, oxyde d'uranium, eau lourde*) was commissioned successfully (Mongin and Delahaye 2020, 18–20). The influence of ZOE on public opinion and politics in France was extraordinary, and it became a major symbol of the renaissance of nuclear research there (Bossière 1948a; 1948b; 1948c). However, it was not very significant in the sense of generating nuclear energy. According to Lew Kowarski, who was involved in the construction of the first nuclear reactor in Canada and became head of the ZOE research and development team, such zero-power reactors were relatively simple devices that only required the pouring of heavy water into a "bath" and putting in uranium oxide, without the need to know the exact proportions (Pinault 2000, 417). Therefore, ZOE was essentially an experimental reactor, and the radiation that it produced used for experimentation, for example, as a neutron source.[12] To meet further experimental needs, in 1949, the CEA began developing a second experimental reactor, designated P2. The fission fuel was natural uranium, which posed the same problems as those for the ZOE: for instance, France did not produce heavy water, which had to be imported from Norway, and the quantities used were strictly controlled. Such difficulties led the CEA to adopt an innovative solution: the cooling of the fuel elements was accomplished by circulating compressed gas.[13] During the development of P2, Joliot-Curie was removed from office in 1950 because of his Communist Party membership, and his role in the international peace movement. Francis Perrin, who succeeded Joliot-Curie, had opposed the construction of plutonium-producing reactors in July 1951 to avoid the possible military use of nuclear science (Mongin 1997, 118–120). However, when P2, the first reactor to use pressurized gas for cooling in the world, was successfully commissioned in 1952, its objectives included, besides being a very useful experimental reactor, the production of

12 Rapport de CEA, no. 227, 1953.
13 Rapport de CEA-R2696, Genève 1964, A Conf.28/P/33.

radioactive elements (including 500 g plutonium/year).[14]

In fact, by August 1951, Felix Gaillard, secretary of state in charge of the affairs of the CEA, succeeded in convincing the researchers to adopt an ambitious plan for the rapid realization of civilian nuclear energy. This put the large-scale production of plutonium on the agenda. A series of meetings of the CEA from September to October 1951 defined the basic lines of future civil nuclear energy research and development. Gaillard believed that if the budget for the CEA was to be secured, it was essential to demonstrate that nuclear research would soon have the capacity to be oriented toward practical industrial applications, and not just be purely for academic purposes. Gaillard pointed out the need for a long-term plan for the CEA, and the need to choose between plutonium and enriched uranium for the technology roadmap (Mongin 1997, 118–120). With regard to the matter of nuclear fuel selection, the CEA's scientists had little knowledge of enriched uranium and obtaining this fissile material would also require the establishment of an isotope separation plant, funds for which would be difficult to secure from the government. In addition, France, which had just achieved uranium self-sufficiency, did not have enough natural uranium to support enriched uranium production. On the contrary, they had acquired knowledge of plutonium extraction from irradiated natural uranium during World War II, when Bertrand Goldschmidt was involved in the Manhattan Project in Canada. Kowarski noted that enriching natural uranium with small amounts of plutonium made it possible to build reactors, while pure plutonium could be used to build breeder reactors and to explore slow neutron reactors using only plutonium as fuel. Thus, the enrichment of uranium should be part of a long-term plan, but if France needed to achieve industrial use of nuclear energy quickly, it must first achieve the production of a few kilograms of plutonium.[15] After a comparison with the US and British nuclear energy programs of the time, Perrin pointed out in his report that when the production of plutonium and electrical energy took place in a reactor using slightly enriched U-235, it would increase reactivity and allow operation at high temperatures. Perrin suggested that similar results could be achieved if plutonium produced from inefficient primary reactors could enrich uranium for use in follow-on reactors. Such an approach had been used in the British nuclear energy power program and was therefore a strong endorsement of the CEA's choice. Perrin considered it difficult to pursue both roadmaps, and the fact that the United Kingdom, who had mastered isotope separation technology, chose plutonium reinforced the viability of the CEA's project.[16] This then became a principle on which the French civilian nuclear energy program was based. Of course, this also required consideration of the economics of primary reactors: the production of large amounts of

14 Ibid.; La Pile P2: Seconde étape vers l'autonomie atomique, *Science et Vie*, le juillet 1953.
15 Rapport de CEA, no. 145, le juillet 1952.
16 Rapport de CEA, no. 485, le octobre 1955.

plutonium without consuming too much natural uranium. In this context, the choice of moderator became more critical. In his report in late 1951, Kowarski showed that in experimental reactors it is advantageous to use heavy water as a moderator because it absorbs fewer neutrons and has a lower critical mass of uranium. A heavy water-uranium oxide reactor for industrial use requires more uranium than an experimental reactor, and therefore more moderator. In this case, heavy water reactors lose the advantage of having small critical mass. The price of heavy water also became prohibitive when it came to building reactors with hundreds of tons of moderator. He believed that this was the reason why there were no plans to build large heavy water reactors worldwide. Thus, France was left with no other choice. If it wanted to carry out a civilian nuclear energy project using plutonium, it would have to use graphite as a moderator to build industrial-type reactors. He concluded that a graphite-natural uranium reactor with high-pressure gas cooling could achieve a total power output of 45,000–50,000 kW at 500 kW/ton, the consumption of natural uranium could be kept below 100 tons, and 15 kg of plutonium could be produced annually.[17]

A consensus finally crystallized in November 1951: firstly, a 45,000 kW graphite gas reactor would need to be built in order to produce 15 kg of plutonium per year, which was expected to consume 90 tons of uranium and 2000 tons of graphite. Secondly, the second reactor would be twice as powerful as the first. Its preparation should start in 1953 with construction completed in 1957. In addition, a plutonium extraction plant would need to be built. Its capacity should be at least equal to the output of the two planned reactors, namely 45 kilograms per year. Thirdly, the estimated costs for this CEA project, including uranium exploration and mining, construction of other facilities, and personnel expenses, would be 42.85 billion francs (Mongin 1997, 124). It is easy to see that these details are not far from those given in Kowalski's report in 1951. On July 3, 1952, after a long discussion in the *Assemblée nationale*, the project was approved, but the funds allocated were reduced to 37.7 billion francs, spread over five years. This project was also known as the Five-Year Plan for Nuclear Energy.[18]

The adoption and implementation of the Five-Year Plan for Nuclear Energy was a key step in the development of civilian nuclear energy in France. However, although the military use of plutonium was not mentioned in the CEA's proposal or in parliamentary discussions, which merely expressed the expectation that France would become scientifically and technologically self-sufficient and solve its energy problems, and even that the subsequent research facilities would be located near major university centers, the Plan in fact pushed France to the crossroads of the peaceful and military uses of nuclear science. By the standards of the world's first plutonium bomb 45 kilograms of plutonium would have given France enough fissile material to produce

17 Rapport de CEA, no. 145, le juillet 1952.
18 Assemblée nationale, feuilleton no. 158 du jeudi, le 3 juillet 1952.

five to six atomic bombs by the end of the 1950s (Jurgensen and Mongin 2018, 165). Thus, the Five-Year Plan was a clear step towards the development of nuclear weapons, setting the technology roadmap for France's early nuclear weapons and providing the leverage for adjustments in military and foreign policy. Another factor for choosing the plutonium bomb was the time limit. In 1956, the agreement between the military and the CEA called for the completion of the first nuclear weapon test within the period of 1957–1961. The Five-Year Plan could only begin to benefit the atomic bomb project from 1957 or 1958. Indeed, the planned plutonium extraction plant did not supply fissile material to the military agencies of the CEA until November 1958. In this context, the plutonium bomb became a relatively safe option, and could also serve, in part, as a guarantee of self-reliance during the development of the atomic bomb, as both the United States and Britain prohibited the supply of high-enriched uranium to France for making nuclear weapons.[19]

4 The R&D of France's first atomic bomb

How France made the decision to build its first atomic bomb has been well discussed among the international academic community: after the First Indochina War, at a meeting convened by the Mendes-France administration on December 26, 1954, the policy of developing nuclear submarines and secretly developing the atomic bomb was confirmed, and on December 28, the *Bureau d'études générales* (BEG), as a secret organ of the CEA, was established. On May 20, 1955, the Edgar Faure administration signed a secret agreement to provide a budget of 100 billion francs for the military use of nuclear energy (Duval and Mongin 1993, 39). After the Suez Crisis, the Guy Mollet administration signed a supplementary agreement for a period of five years (1957–1961) on November 30, 1956, charging the CEA with the task of building the first nuclear device, and requesting the military to provide the necessary assistance for the test (Mongin and Delahaye 2020, 21). At this point, the Fourth Republic had finally made the important decision for R&D of the atomic bomb, in which the CEA took the lead. In February 1957, the BEG was reorganized as the *Direction des Techniques Nouvelles* (DTN). By May 1957, most of the French political parties recognized nuclear weapons as a necessary means of preserving the country's independence.[20] The military R&D organization of the CEA was reorganized again in September 1958, and the DTN was replaced by the *Direction des Applications Militaires* (DAM) (Mongin and Delahaye 2020, 39).

19 Office of Scientific Intelligence, Central Intelligence Agency, The French Nuclear Weapons Program, November 19, 1959. Classification Redacted. Freedom of Information Act Request.

20 Office of Current Intelligence, Central Intelligence Agency, "French Position on Disarmament May Be Shifting," Current Intelligence Bulletin, May 29, 1957. Top Secret. CIA Records Search Tool (CREST) Collection, NARA.

The development of the atomic bomb was a great challenge for France. In terms of the international situation, the Eisenhower administration followed the principle of not transferring nuclear weapons technology to any country after World War II. However, it had different attitudes toward Britain and France. The US Congress passed an amendment on July 2, 1958, allowing the provision of nuclear industry information to countries that had made substantial progress in the field of nuclear weapons. Considering that Britain had completed its first nuclear weapon test in 1952, this clearly excluded France from assistance (Yao 2009). The deep-rooted and underlying problem was that the United States did not want a special partnership with France. It also was not willing to form a permanent US-British-French trilateral political and military structure, was not willing to give France the right to decide on the use of nuclear weapons in the North Atlantic Treaty Organization (NATO), and even demanded that France seriously consider the costs and responsibilities of becoming a nuclear power. A France with an independent nuclear deterrent would not only reduce its dependence on the United States, but would also shake NATO's established alliances. As a result, Paris's demands for nuclear weapons technology had not been met by Washington.[21] The American attitude led France to reject the deployment of any nuclear weapons on its territory that it did not have the right to control.[22] In this isolated situation, first, there were many core technologies that France needed to figure out, as well as problems to overcome, some that basically no one had had to face before. Second, there was a shortage of professional staff. Both factors could lead to delays in the R&D.[23] At the same time, this was a watershed in the development of the CEA. As a result, its military and civilian research programs were distinguished not only in terms of mission but also location, finally forming a "civil-military complex."

The BEG, approved by the Mendes-France Administration in December 1954, could not locate its infrastructure in an existing CEA's facility for reasons of confidentiality. On June 3, 1955, the CEA and the *Service des Poudres* signed an agreement for a period of five years, with the possibility of renewal. The agreement provided for the establishment and development by the *Service des Poudres* of a research facility at Fort

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21 Dispatch from the Embassy in France to the Department of State, no. 2129, Paris, June 11, 1958. Subject: De Gaulle Government and French Atomic Energy Policy: Conversation with De Rose, Foreign Office; Memorandum from the Assistant Secretary of State for European Affairs (Merchant) to Secretary of State Herter, May 5, 1959. Subject: U.S.-French Relations; Memorandum of Conversation. US/MC/41, Paris, May 20, 1960, 11:30 a.m. Subject: Nuclear Energy Cooperation with France (Meeting of Chiefs of State and Heads of Government—Paris, May, 1960). *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2.*

22 Document 121. Editorial Note. *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2.*

23 Office of Current Intelligence, Central Intelligence Agency. "The French Nuclear Energy Program," Current Intelligence Weekly Summary, January 28, 1960. Classification Redacted. Freedom of Information Act Request.

de Vaujours, north of Paris, to conduct all research on explosives related to nuclear weapons. The Vaujours Center was headed by Georges Barguillet and had three divisions: the Device Division, the Physics Division, and the Theory Division. The Device Division, headed by Andreé Cachin, was in charge of the chemical laboratories and fabrication workshops, and worked with the Physics Division, headed by Jean Viard and Jacques Thouvenin, to ensure the development of various explosive structures. The Physics Division was equipped with all the rapid observation tools needed for experimental explosive research. The two divisions also used the bunkers at Fort de Vaujours. One was designed to carry out dangerous experimental activities from a distance, and the other was converted into a firing point. The Theory Division, headed by Jean Berger, was charged with perfecting implosion techniques, and devising the graphic and numeric methods needed to restore and extrapolate the results of the explosion (Pô 2001, 65–66). Research in this field by the *Service des Poudres* had been underway since the end of World War II and they had a basic handle on the problem of explosive devices that produce a centripetal spherical detonation wave (*l'onde de détonation sphérique centripète*) (Mongin 1989). In order to obtain this kind of wave, the Vaujours Center designed a cone generator "combining an external shell of fast explosive, with an internal loading of slower explosive, the shape affecting that of a pointed tip of revolution, and primed in point by a traditional detonator" (Billaud 2016e, 40). The velocity ratio of slow/fast explosives was kept as low as possible to avoid excessive generator size and the risk of fragility (ibid.). However, there were still many problems to be solved and in-depth theoretical studies needed. Some of the results derived from theory at the Vaujours Center could be verified experimentally. During these experiments, the nuclear material was replaced by inert materials with properties similar to plutonium. The French made extensive use of photographic, ultra-high-speed photography, flash X-rays, and all the resources of fast electrons and sensors to determine precisely the values of the various parameters involved in the process and, in particular, to verify that the results fitted the theory. In fact, the small sphere implosion experiments by the French could not precisely track the external radius of a sphere versus time. Vaujour's physicists were unable to give precise details of the intermediate stages and could only provide estimates of the time of spherical contraction. However, they believed that the plutonium would be strongly compressed at the end of the implosion. This would change the mass setting for plutonium in the first French nuclear device constructed in 1959 (Billaud 2016a, 54–55). Problems involving thermodynamics, hydrodynamics, or solid-state physics, on the other hand, required complex computer calculations to specify the evolution of the system in all useful stages (Pô 2001, 104). The Vaujours Center made very fast progress. By 1957–1958, they had a good understanding of the interactions between the implosion system and the metallic structure to be compressed, and a viable and efficient combination of techniques from the point of view of dynamics and adaptive structures, resulting in various implosion systems corresponding to different assumed material masses. Combining all the data, researchers of the B3 selected the largest size implosion system available provided by the Vaujours Center. Although the mass of the plutonium core eventually changed, the implosion system retained the initial choice (Billaud 2016a, 51–52). Compared to the world's first plutonium bomb—the "Gadget" of the United States—which used thirty-two centripetal spherical detonation wave generators, France's first atomic bomb, the M1, had far fewer and produced a better and more efficient waveform (Billaud 2016e, 44–45). This was the first breakthrough in the development of the French atomic bomb.

The second site, code-named B III, was responsible for much of the development of France's first atomic bomb. The purchase of the land for B III was financed by the *Service de documentation extérieure et de contre-espionnage* (SDECE), the French national security agency at that time (Adamson 2005, 529–530), and was located thirty-five kilometers south of Paris in Bruyeres-le-Chatel, not far from the CEA's original civil R&D centers, B I and B II. The name of the institution and its geographical proximity also served as a cover for the secret work carried out there on the atomic bomb. In the third quarter of 1955, B III developed its overall plan. The construction of the first buildings began in December. B III was headed by Pierre Laurent (Billaud 2016b, 25–26), and the Experimental Nuclear Physics Division was created on September 1, 1955, under the direction of Pierre Billaud. Due to time constraints, this Division moved into B III in July 1956 and installed a 2 MeV Van de Graaff Accelerator in a temporary building to provide neutron reflection capabilities on every conceivable metal, including natural uranium (Billaud 2016a, 51–52). In late 1956, the Mathematical Physics Division was established under the direction of Jean Salmon. In January 1957, the Metallurgy Division was created at B III, headed by Jean Ferry. In July of the same year, the Chemistry Division was created, headed by physicist Eugene Freiling, who was from the *Centre national de la recherche scientifique* (CNRS). For processing more fissile materials and to carry out "cold explosions" tests with explosives and materials as close as possible to plutonium, in 1957 B III acquired 500 hectares of land 15 km from Reims, and in 1958, 175 hectares of land at Valduc (Pô 2001, 67).

The French initial concept for the plutonium bomb was simple. They wanted to obtain an explosion by placing enough fissile material in a supercritical situation, followed by a neutron-induced chain reaction (Billaud 2016a, 50–51). The use of implosion was a way to simplify the design. Implosion was thought to allow rapid compression of the plutonium core. Therefore, the problem that had to be solved was to find the approximate time range for compressing the core and then provide the necessary neutrons (ibid., 55–57). In this situation, several parameters needed to be determined, such as the cross-section of the fissile material, critical mass, detonation condition, and the rate of proliferation of neutrons in the chain reaction (Mongin 1997, 268–270; Pô 2001, 101). These were largely unknown areas for the French, but all were essential data for the design of the device. For example, the study of the compression of plutonium, which allowed a nuclear device to transition from a subcritical to a supercritical state, was extremely complex and required the use of very precise calculations. The mass of plutonium placed in the device had to be sufficient to reach the critical threshold at assembly, but not so large as to increase the risk of failure due to excess neutrons, and to avoid excessive energy release by the explosion. At that time, the French targeted a 25 kilotons of TNT equivalent for the first nuclear device, slightly higher than the world's first atomic bombs. B III had set the mass of plutonium core at *m1* in 1957, but by late 1959 had made a significant change to a smaller mass—*m2*. This change was based on data obtained from American counterparts, as well as on the Vaujours Center's analysis of the compression of plutonium by implosion: a strong compression would result in continuous enrichment, and the density of plutonium would increase significantly, reaching 2–3 times higher than its resting state, which would make it possible to exceed the safety limits for the explosive power of the nuclear device, since the height of the tower set up at the test site had already been determined and could not be changed at will. For this reason, the mass of the plutonium core needed to be reduced (Billaud 2016e, 42). The Theory Division of the Vaujours Center applied the equations of state for plutonium and uranium transplanted from suitable base metals to measure the instantaneous local density of alpha particles in the relevant time range. This method was adopted by the Mathematical Physics Division of B III as the starting data for calculating point-by-point alpha particles, reconstructing the curve of alpha particles required for the control of the neutron source, and demonstrating that the choice of *m2* was feasible (Billaud 2016a, 55–57). The final determination of the mass of the plutonium core became another breakthrough in the development of the French atomic bomb. However, the measurements only indicated that M1 could be successfully detonated, and the French had not yet completed an accurate prediction of the energy released by the explosion by the time the nuclear device had been assembled. This work was in fact very important, as it determined the organization of the test and the precautions taken to ensure the safety of personnel (Pô 2001, 101). The reason for this was that the Mathematical Physics Division had encountered difficulties in developing computational codes. For this purpose, they were equipped with the latest and most powerful Bull and IBM computers of the time[24] in order to design physical numerical models to describe the fission efficiency under extreme temperature and pressure conditions (Pô 2001, 101). The new IBM computers were put in place in 1959 (Schwerer

24 Allocution du Général Buchalet le 13 Février 1960 (Billaud 2016c, 60–61).

2016, 184–185) though this was still too late. It was not until the day before the M1 detonation that an accurate measurement of the energy was transmitted to the test site, and its range was determined to be 40–60 kilotons of TNT equivalent (Billaud 2016a, 55–57).

B III set up a neutron reflector (*le réflecteur de neutrons*), or tamper (*le tampeur*), for the plutonium bomb, which also acted as a decelerator for the expansion of the system around the fission core, thus enhancing the supercriticality (reflection effect) and the fission product yield (sieve effect), allowing for a longer duration, more energy, and higher efficiency of the explosion. When the French set the plutonium core mass at *m1*, the question of the tamper was settled. The tamper was made of natural uranium. Because of its high density, natural uranium was an excellent neutron reflector and tamper that could also produce some additional fission, and logically it should have: "1. A thickness after gathering at least of the order of the mean neutron scattering free path, several times stronger if possible (reflection effect); 2. a large mass compared to the value *m1* (sieve effect). Since there is nothing to lose by increasing this mass, a suitable value was finally adopted" (ibid., 50–52). In addition, supercriticality had to be achieved without adding neutrons to avoid premature chain reactions which lead to poor performance. Since plutonium emits neutrons all the time, the time between the transition to the critical state and the final supercritical state had to be reduced sufficiently to make the probability of premature initiation negligible. The French thus used a high-power chemical explosive to set the fissile material and the accompanying tamper in motion. Like the implosion system, the tamper was also not influenced by the change in the mass of plutonium core (ibid., 50–52).

Another important task of B III was to be responsible for the forging of plutonium. Although supported by the civilian agencies of the CEA, the technology for handling, forming, and processing plutonium for military purposes remained unknown to the French, so the civilian scientists could provide little support in this area. The CEA's plutonium extraction plant at Marcoule (UP1) produced its first gram of plutonium in July 1958 and began to deliver fissile materials to B III from November 1958. B III divided its research into three phases. The first phase involved understanding the physical properties of plutonium alloys for military proposes and designing the appropriate equipment. The second focused on developing manufacturing techniques. Time constraints meant that Phase I was conducted simultaneously with Phase II using very small amounts of plutonium. The third, the actual manufacturing phase, required an extension of the experimental results from the first two phases and could involve up to a dozen grams of plutonium (ibid., 55–57). Since the extraction plant would not produce its first plutonium ingot until February 1959 (Amiard 2022, 171), the B III site at Valduc processed a batch of oxalate in early 1959, ensuring that researchers could conduct technical studies on plutonium metal. In June 1959, B III achieved the first experimental casting of more than one kilogram of plutonium. After determining the need to reduce the mass of fissile material, the Metallurgy Division simplified the casting of the core, and the part connecting the new plutonium core to the tamper was modified accordingly (Billaud 2016a, 55–57). The remaining plutonium was made for the second French atomic bomb, called P1, which also served as a backup device for the first nuclear weapon test (ibid., 59). All this work carried significant risks, and B III designed a three-story underground laboratory protected by tens of centimeters of concrete. This laboratory was equipped with a very effective ventilation system, could achieve negative pressure relative to external pressures and overpressure relative to the work units (*les cellules de travail*), as well as handle and store tens of kilograms of plutonium. This provided the researchers with a significant level of safety and health protection. Due to its proximity to a flight test center, its top floor was also retrofitted with facilities that could withstand aircraft impact (Adamson 2005, 471–472; Mongin 1997, 270). In addition, the researchers needed to keep the plutonium subcritical under all normal conditions, which imposed several operational constraints, leading to close collaboration between the physicists and mathematicians at BIII (Pô 2001, 102–103).

In January 1959, the CEA acquired the Limeil Center from the *Direction des Études et Fabrications d'Armement* (DEFA), located in Villeneuve-Saint-Georges. From 1955 to 1958, the *Section atomique* of the DEFA used this site as a test site and for nuclear physics research. The Center solved the problem of the neutron source for the atomic bomb. In 1955, researchers there discovered that the bomb required a stream of neutrons to explode. This was an important discovery for the French, who had previously believed that fissile material could explode as soon as it reached a supercritical state (Mongin 1997, 338). However, given the still-competitive relationship between the *Section atomique* and the CEA at this time, due to a lack of relevant documents it remains difficult to say how the B III researchers were informed of the need to develop the technology of the neutron source. In fact, the leader of the *Section atomique* insisted on a tight-knit team, forbidding them from contact with the CEA, and for the time being kept the CEA at bay (Adamson 2005, 532). For the neutron source, two approaches were proposed by the Limeil Center. One was a source with low neutron production, internal to the device with axial concentration. The other had a source with high neutron production, outside the device (Pô 2001, 101). The latter proved to be the only viable approach for an implosion-type nuclear device for the French, because the engineers at the Limeil Center did not have the capability to design an internal source that would function reliably and reproducibly at the center of the implosion. Initially, the Center did not focus on the development of an external source, but in late 1957, when it became known that B III was having trouble with producing a neutron source, the development of an external source became a top priority. B III also began working on a neutron source in early 1957, knowing fully well that the neutrons used to initiate the chain reaction would have to be delivered to the plutonium in a very short time after supercriticality was achieved, according to the data on implosions provided by the Vaujours Center. The priority of B III was also an internal source: "it seemed quite natural, with an initially hollow Pu core, to make the neutron emission dependent on the concentration of Pu, by placing a pair of neutron generators (alpha particle emitter-targets) in the starting cavity, under a particular geometry capable of increasing the yield of alpha-n reactions as the cavity resorbs at the end of concentration" (Billaud 2016a, 52–53). However, the B III researchers were unable to solve the geometry problem, and "it was not clear how, if at all, sufficient experimental guarantees could be obtained concerning the value of the flow rate and the reproducibility of the performance under real conditions" (ibid.). Therefore, this plan could only produce a continuous beam, but it might come dangerously close to declenching an early chain reaction (Adamson 2005, 532). When André Chaudière, one of the researchers of the Limeil Center, took charge of research on the external source, he led a small team trained on the neutron problem and without any influence from *a priori* theories or experiments (Bonnet 2000, 22). "Before the end of spring 1958, a machine of a few liters of volume was almost operational" (Pô 2001, 101). It was designed to be placed outside the nuclear device to prevent it from being destroyed by an implosion prior to a concentrated ejection of neutrons. It was based on an accelerator-type neutron generator that implemented the deuterium-tritium reaction in the form of a high-voltage discharge tube (Billaud 2016e, 41). B III agreed to this option and believed that "the performance factor that might be missing would surely be made up during the development of the device." In addition, the use of an external neutron source made it relatively easy to "find the moment of initiation after the disappearance of the cavity." In an optimal setup, the explosion could be kept at the energy target and the plutonium core mass could be reduced (Billaud 2016a, 52–53). This external neutron source became a significant innovation of the first French atomic bomb.

In the CEA, the separation of two kinds of R&D also led to the recruitment of members of the military branch largely independent from the civilian branch, with only the odd exceptional case in which researchers responsible for civilian projects were included. Through recruitment by the *Service des Poudres*, BEG staff reached 70 by the end of 1955, increased by another 120 in 1956, and reached 600 by 1957 (Mongin 1997, 270). When DAM was created in September 1958, it numbered just shy of 1000 (Pô 2001, 85). The internal security services scrutinized all applicants to prevent infiltration by spies. This French secrecy was effective. The United States were unable to acquire accurate information about the agencies and personnel involved in the development of the French atomic bomb.[25] Recruits were also paid five percent more than those involved in civilian R&D as compensation for limiting their day-to-day activities, which

25 Office of Scientific Intelligence, Central Intelligence Agency, The French Nuclear Weapons Program, November 19, 1959. Classification Redacted. Freedom of Information Act Request.

included the publication of results, something very important to scientists. At the same time, the CEA limited employee representation as much as possible to prevent additional factors from disrupting military activities. Of course, Guillaumat's strategy could not separate completely civilian and military R&D, and this so-called separation had more of a political and administrative significance in terms of secrecy provision. Not only did the CEA's civilian agencies provide intellectual and technical training for military recruits (Pô 2001, 58–59), but the development of the atomic bomb also relied on civilian research. The "Five-Year Plan for Nuclear Energy" became a reality from 1956 onward, with the G1 and G2 reactors being successfully commissioned in January 1956 and July 1958 (Ferrand 2016, 385). The plutonium extraction plant at Marcoule was commissioned in January 1958. It extracted the plutonium gathered in the irradiated fuel from both reactors, delivering it to the B III laboratories from November 1958, thus ensuring the supply of fissile material for the development of the bomb (Chevallier 2016, 390–391). The military sector often maintained communication with the civilian sector in the field of plutonium metallurgy. The civilian agencies of the CEA had already conducted significant research on plutonium properties and metallurgy for application in breeder reactors, thus providing the military sector with technical knowledge of plutonium handling. In addition, the DAM used the accelerators and made important measurements, especially those on fission and capture cross sections. In turn, the military sector agreed to the civilian sector being allowed to use facilities of the B III for scientific work on plutonium, for example, running calculations on DAM's computers (Pô 2001, 101–102; Adamson 2005, 568). In addition, a scientific committee was established to oversee military R&D, in which officials and scientists from both sides often sat side-by-side (Pô 2001, 94–95).

The "Common Core," formed by a public institution—the CEA, with the assistance of the military, became an important guarantee for the success of France's first nuclear device and formed the basic model for the research and development of future French nuclear weapons.

5 Site selection, organization, and monitoring of the first French nuclear weapon test

While the site selection, organization, and security for the first French nuclear weapon test were jointly negotiated between the military and the CEA, the military had greater responsibility. In February 1956, the French Army set up an inter-army group, the *Groupe d'étude des expérimentations spéciales*, to explore the organization of the test and to train military personnel (Pô 2001, 134). In March 1957, under the coordination of the *Comité des applications militaires de l'énergie atomique* (CAMEA), the military and the CEA agreed to redistribute tasks and to establish new working groups. One was the *Groupe* *mixte des expérimentations nucléaires*, which dealt with matters for which the CEA and the military were jointly responsible. Another, the *Groupe militaire des expérimentations nucléaires*, studied logistics, ground and air safety, detection, and decontamination. This group was renamed again in February 1958 as the *Commandement interarmées des armes spéciales* (CIAS) (Mongin 1997, 339).

Soon after its foundation, in 1957, the *Groupe mixte des expérimentations nucléaires* raised the issue of a site for the nuclear test. Three sites were available, one in Polynesia, one on the Kerguelen Islands, and one in the Algerian Sahara Desert. At this time, these territories were all overseas departments of France. Finally, in July of the same year, the French chose Reggane, located in Tanezrouf in the Sahara Desert. There were two reasons for this choice. First, the region was virtually uninhabited due to its hot, arid climate, and it was far from any populated areas. The nearest town, Colomb-Béchar, with a resident population of about 18,000, was 700 kilometers south of Reggane. Second, there were favorable geological and meteorological conditions. Along with its desert features, the region has good climatic conditions for most of the year, with the main wind system allowing radioactive dust to drift eastward, where there was essentially no human activity.[26] It is noteworthy that prior atmospheric nuclear tests by the United States, the Soviet Union, and the United Kingdom had also been conducted in desert areas: Nevada, Semipalatinsk, and South Australia. This may have provided some reference for France's choice. Before Algeria gained independence in July 1962, France conducted a total of four nuclear weapons tests at Reggane.

The test site was located in Hamoudia, known as the *Centre Saharien d'Expérimentations Militaires* (CSEM). Construction on an airport, water supply wells, and a living base for personnel began in November 1957. At its peak, more than 10,000 military and scientific personnel were stationed there (Mongin 1997, 339). The French first nuclear weapon test was code-named *Gerboise Bleue*. The detonation site, the *point zéro*, was about 70 kilometers southwest of Reggane (Billaud 2016f, 191). The M1 bomb was placed on a 100-meter-high tower. It "did not look like a bomb at all, but rather a very large and complex experimental device with many wires that allowed for various measurements" (Jamet 2016, 74). To the right of the M1 were the cables for the rapid transmission of reaction data to distant underground bunkers (Billaud 2016a, 56). These bunkers, of which there were two, were used to house close-up measurement equipment, one for diagnostics of the nuclear device and the other for taking close-up photos of the moment after detonation (Billaud 2016f, 191).

Observation of nuclear explosions was an important part of nuclear testing, and

26 M. Christian Bataille, Député et M. Henri Revol, Sénateur. Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques-Rapport No. 207: Les incidences environnementales et sanitaires des essais nucléaires effectués par la France entre 1960 et 1996 et éléments de comparaison avec les essais des autres puissances nucléaires. Sénat, 2001/2002. 20.

France relied on the Americans for help. In the period of the Eisenhower administration, the overall policy toward France was relatively lenient, despite restrictions, and Gaullism had not yet caused tensions between the two countries. As a result, the United States neither encouraged nor actively opposed French nuclear weapons projects. France had access to some American knowledge and technology in the nuclear military field not directly related to the development of atomic weapons. This can be seen as a consideration to keep France from taking further independent action. During his visit to France in July 1958, the Secretary of State indicated to de Gaulle that the United States was prepared to have French forces adequately trained in the use of nuclear weapons. Subject to the interests of the alliance, the United States could also help France develop reactors for nuclear submarines if France so wished.[27] Through diplomatic channels, the French army and the CEA were given the opportunity to visit American military nuclear facilities and to negotiate the transfer of technology. The delegation, composed of military officers, medical personnel, physicists, and other scientists, traveled to the United States in February 1958 for a two-week visit under the code name "Aurora", with positive results (ibid.). The United States agreed to provide enriched uranium for the land-based test site for French nuclear submarines.[28] Of relevance to the operation of nuclear weapons tests and observation equipment, the French visited the Nevada Test Site and interacted with the technicians and scientists therein. The French delegation was even able to participate in preparations for underground nuclear weapons tests. The Americans explained to them how gamma rays from nuclear devices were detected at close range and instantly diagnosed, and how electromagnetic interference from all the cables on the test site could be avoided so as not to interfere with the measurements. The Americans also demonstrated how to record the test explosions from a remote bunker (Billaud 2016d, 31–32). The French delegation also went to the offices of EG&G (Edgerton, Gemerhausen, and Grier) in Las Vegas to sign an agreement to purchase instruments including oscilloscopes. The company had been established in 1947 at the request of the US Atomic Energy Commission as a prime contractor to provide equipment for the observation of nuclear tests.[29] The equipment was very useful to France for studying the physical phenomena generated by the explosion of nuclear devices and saved "millions of dollars" and months of testing and research.[30] At the same time, the French collected "countless

27 Memorandum of Conversation, the Secretary's talks with General de Gaulle in Paris, Paris, July 5, 1958. In *Foreign Relations of The United States, 1958–1960, Western Europe, Volume VII, Part 2*.
28 Memorandum of Conversation, General Buchalet's Visit to the United States, February 21, 1958. In *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2*.
29 EG&G the Company: 1947 Onwards. http://edgerton-digital-collections.org/docs-life/egg-the-company
30 Memorandum of Conversation, General Buchalet's Visit to the United States, February 21, 1958. In *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2*.

pieces of valuable information on methods of operation, materials and suppliers' addresses" (Billaud 2016d, 31–32). In the words of those involved in the first French nuclear weapon test at the time, the American role in this regard was "crucial, if not decisive" (Pô 2001, 134). By the time of the presidency of John F. Kennedy, when bilateral relations grew frosty and the United States refused to provide relevant equipment to France, the French were not much affected, because they had developed corresponding equipment based on American instruments (Pô 2001, 134).

Of course, not all the equipment required was dependent on the United States. The French also had self-developed means of measurement. The *Laboratoire Central de l'Armement* was responsible for developing equipment to capture information from the nuclear explosion within very short exposure times, as well as ultra-high-speed photographic instruments, and was responsible for all optical measurements at the test site. Its team would go to recover the film shortly after the nuclear explosion and other recordings a few kilometers away from the tower (Jamet 2016, 75). The French also designed a smoke rocket system to visualize the shock waves of the explosion. Adoption of this method most likely drew inspiration from the fact that the United States had been using smoke rockets instead of balloons to observe the shock waves from their own tests since the early 1950s. The French smoke rockets were of two types: one type angled at 60 degrees and one straight up, both types needing to reach an altitude of 1200 meters or more and leave a long smoke trail. The French Air Force was responsible for the slanting type, while the DEFA was responsible for the vertical type, designated AT1. Each rocket was 150 mm in diameter and had holes on both sides of the arrow-shaped body to allow smoke to escape (ibid., 63–66, 68). The military verified the reliability of the system with magnesium bombs strapped to hydrogen balloons (ibid., 69–70). All rockets were evenly spaced at 100-meter intervals in a straight line from the tower, the closest rocket being only 200 meters from the tower (ibid., 72). In addition, the French placed "various vehicles, tanks, guns, aircraft, radar equipment, and even a whole army of mannequins in different uniforms" around the tower to test the effects of the nuclear explosion on these materials at different distances (ibid., 71). The Air Force also sent planes into the clouds to collect radioactive fallout after the explosion.

Since atmospheric nuclear tests in tower form was adopted, radioactive contamination was bound to result. A set of rules and practices for radioactivity monitoring to prevent harm to the environment and people from the tests was developed by the *Commission Consultative de Contrôle* (CCC), established in 1958. Monitoring was carried out at two levels. Systematic and repeated measurements of soil and air contamination were required in the vicinity of the test and along the fallout axis where significant contamination was likely to occur. These measurements were carried out by specialized units on land or by aircraft to delineate the radioactive fallout zone. In areas far from the test site, where direct measurement of radioactivity was not possible, samples (such as air and soil) were taken and sent to laboratories for fine measurement. The French set up such a monitoring network mainly in French-speaking Africa, joined by several embassies, thus enabling a global assessment.[31]

Since meteorological conditions were crucial for determining the time of detonation, the French also set up a meteorological monitoring system. In addition to the data provided by the global network, the *Groupement Opérationnel des Expérimentations Nucléaires* (GOEN) set up a radar system covering the entire Sahara to provide high-altitude observations in the region. In turn, local stations measured data at the lower altitude. "Meteorological measurements are very closely linked to the chronology of operations in preparation for the explosion, before and after the explosion. . . . Before the explosion, the forecasts are improved to provide a more precise and reliable indication based on 48-hour forecasts. . . . The fallout maps applied to the Sahara then very clearly indicate the risk zones or areas where there is no risk. . . . The decision to detonate a nuclear bomb depends only on the weather. One must seize the good opportunities offered by forecasts in the lower layers, which tend to be very erratic" (ibid., 22).

When the weather forecast reported that there would be strong winds in a very steady direction that would allow the fallout to avoid all areas of human activity, the French decided to detonate M1 at sunrise on February 13, 1960 (Billaud 2016a, 57). At exactly 7:04 a.m., "an unusually bright point of light, visible even through almost impervious glasses, like a blazing sun in daylight, appeared at the top of the tower. Then, instantly, a huge fireball appeared, lasted for two or three seconds, and rose quickly into the sky" (Ailleret 2016, 82). At a measurement point located approximately 100 meters in front of the operations command, the CEA scientists announced two items of data: 75 and 45 kilotons of TNT equivalent. The first was derived by measuring the shock wave and the second by determining the total thermal energy. To guarantee the mission of cloud sampling, the Air Force wanted to collect enough radioactive residue while avoiding the exposure of pilots to intense radiation. The CEA proposed a standard of 50 kilotons for protective measures (Billaud 2016a, 57–58). Shortly after the explosion, researchers went to both of the aforementioned bunkers to recover data, particularly diagnostics of the chain reaction and transient photographs of the fireball, to measure the exponential response of the alpha rays, combined with the timing of the fireball expansion to infer the energy of the explosion (Billaud 2016f, 193). By the afternoon, the French had calculated the energy released by the explosion of M1: about 60 kilotons (Billaud 2016a, 57–58), far more than the world's first plutonium bomb "Gadget" and far more than the 20 kilotons estimated by American intelligence in

31 M. Christian Bataille, Député et M. Henri Revol, Sénateur. Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques-Rapport No. 207: Les incidences environnementales et sanitaires des essais nucléaires effectués par la France entre 1960 et 1996 et éléments de comparaison avec les essais des autres puissances nucléaires. Sénat, 2001/2002, 23–24.

1959.[32] The radiation monitoring system was also verified. A contaminated zone, about 150 km long, was delineated. Participants in this test were clearly informed about the conditions under which they could enter and leave the contaminated area.[33] The operation *Gerboise Bleue* was a success.

The successful test was the result of the more than four years of hard work by researchers and represented the entry of the newly established Fifth Republic into the rank of counties with nuclear weapons. It became a symbol that General de Gaulle could use for demonstrating France's scientific ability, technical knowledge, and political will to reinvent "the grandeur of France." However, the strongman's long-cherished dream was built on the shoulders of his predecessors. When the Fourth Republic's investment in nuclear science finally bore fruit, times had changed. France still had a long way to go before her *force de frappe* became practical.

6 Conclusion

The first French nuclear device can be characterized by self-reliance. This was based on all the conditions available to France at the time and the choice of the plutonium bomb as the technology roadmap, breaking through the post-World War II American embargo on core nuclear weapons science and technology, and meeting a major national need. As General de Gaulle wrote to Eisenhower in 1959, "France's effort to become a nuclear power—which our country must ensure by its own resources since its Allies do not place sufficient trust in it to help it become such a power—will extend over a long period of time."[34] As Eisenhower predicted, some nations would finally develop nuclear weapon as surely as night and day alternate.[35] Following France, four years later, China exploded its first atomic bomb. These two countries not only serve as important cases to prove the failure of US nuclear nonproliferation policy, but also became diplomatic allies against the Nuclear Test Ban Treaty signed by the United States, Soviet Union, and United Kingdom.

Compared with the first atomic bombs of the United States, Soviet Union, and United Kingdom, M1 displayed several innovations, such as the adoption of a better-designed implosion system, and the adoption of an external neutron source, thus

32 Office of Scientific Intelligence, Central Intelligence Agency, The French Nuclear Weapons Program, November 19, 1959. Classification Redacted. Freedom of Information Act Request.

33 M. Christian BATAILLE, Député. Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques—Rapport No. 179: L'évaluation de la recherche sur la gestion des déchets nucléaires à haute activité—Tome II: Les déchets militaires. Sénat, 1997/1998. In addition, this French official point of view has been challenged by Cooper's (2022) doctoral dissertation.

34 Letter from President de Gaulle to President Eisenhower, Paris, November 24, 1959. In *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2*.

35 Memorandum of Discussion at the 422d Meeting of the National Security Council, October 29, 1959. In *Foreign Relations of the United States, 1958–1960, Western Europe, Volume VII, Part 2*.

achieving the effect of simplifying the structure of the device, reducing the mass of the plutonium core, and increasing fission yield. The fission yield of the M1 reached 50% (Billaud 2016e, 44–45), and the energy released, 60 kilotons of TNT, was much higher than the 20 kilotons of the bombs of the other three countries, setting a record for the maximum yield of the first nuclear test conducted by any country at that time. In addition, the M1 was in no way inferior to the first generation of practical atomic bombs produced by the Soviet Union and Britain, which also were just over 20 kilotons. This is arguably France's outstanding achievement in the field of the military use of nuclear science. American intelligence also gave high marks to the fact that, although Paris received some technical help from the US and Britain, it was only declassified information or test equipment, and thus the success of France's first nuclear weapon test was genuinely the result of self-reliance.[36]

In terms of R&D institutions, the development of M1 differed from the Manhattan Project and the British nuclear weapons project in the Western camp. The Manhattan Project was an international technical and scientific research program led by the United States with the participation of Britain and Canada. The R&D and production works were scattered across more than thirty different locations in the three countries, an unprecedented and unrepeated occurrence in the history of nuclear weapons development in the world. The Project was largely controlled and coordinated by the American military, with the major laboratories being run by universities (Liu, Liu, and Xie 2004, 6–14). After the United States refused to transfer nuclear weapons technology, the United Kingdom, like France, went through a self-sustaining process. In October 1945, the development of nuclear weapons was assigned to the Ministry of Supply, which was responsible for the supply of weapons and equipment to the military and was headed by the Chief of Staff of the Royal Air Force. The Ministry of Supply established the Atomic Energy Research Establishment (AERE), housed in an RAF base, to conduct research and development (Gowing 1988, 40–43). In France, a "common core" was formed: a public institution, the CEA, supplemented by the military. The influence of the French Communist Party and pacifism, two colonial wars, and pressure from the alliance led to the Fourth Republic's hesitancy to develop strategic military technology. Although the military established nuclear research agencies, the exploration of the atomic bomb could only be carried out in secret on the basis of existing knowledge reserves. The research orientation of the CEA was also set in a context of civilian nuclear energy development. It was able to bring together leading nuclear scientists, give them more freedom to explore, and create a more flexible organizational structure. Civilian atomic energy research laid the foundation for the development of nuclear weapons, not only by ensuring the supply of fissile materials,

36 Office of Scientific Intelligence, Central Intelligence Agency, The French Nuclear Weapons Program, November 19, 1959. Classification Redacted. Freedom of Information Act Request.

but also by accumulating technology and talent. This established the strong position of the CEA in France's nuclear sciences, which was able to take the lead after the Fourth Republic decided to develop the atomic bomb. With the B III, and other two centers absorbed from the French Army, the CEA finally became a "civil-military complex."

The development of nuclear weapons is considered the classic model of a Big Science Project. The French case adds to its diversity. The development of the atomic bomb was formed by the interaction between two Big Science Projects in France. In 1952, the R&D on civil atomic power technology, initiated by the Five-Year Plan for Atomic Energy, became the first Big Science Project of nuclear science in France. The graphite gas reactor and the plutonium extraction plant provided the fissile material and data for the atomic bomb and were the most crucial factor in the choice of the plutonium bomb as the technology roadmap. The French atomic bomb project is defined by a process of "conversion from civilian to military." The facilities built by B III for researching plutonium were also available to scientists in the civilian sector of the CEA, providing a mutually beneficial relationship between the military and civilian projects. Certainly, both the institutional innovations and the features of the Big Science Project were motivated by a certain reluctance and passivity on the part of some scientists regarding the military use of nuclear science. As discussed in the previous section, the Five-Year Plan for Atomic Energy and the development of the atomic bomb were driven by the government and were closely related to the internal and external contexts of France, reflecting the increasingly close connection between politics, power, and techno-science after World War II.

Finally, how to make sense of the role played by the information obtained through public materials from the United States and exchanges with American counterparts, in particular, when the data brought back from the US became the source of the B III scientists' proposal to modify the quality of the plutonium core? At the level of the history of knowledge, the French academic community, which was part of the global network of nuclear scientific knowledge dissemination as a receiving node with a system of expertise, was able to clearly recognize and understand the crux of the problem and proceed to solve it. The whole chain of dissemination can be said to be unhindered. This system of knowledge was built, at a superficial level, on the explorations of French scholars in the field of radiological and nuclear sciences. At a deeper level, it was the result of the early institutionalization of science in France. This had led to France's world leadership in nuclear science research in the late nineteenth and early twentieth centuries, achieving knowledge innovation and becoming a node for outward dissemination. Although the work of the Joliot-Curie group was interrupted by the war, it was able to rebuild its research after 1945 based on knowledge disseminated abroad. And even though the United States blocked the transfer of the core technology of nuclear weapons, the French could still find clues among the traces. Therefore, it makes sense that France, as a technological power, was able to become self-sufficient and innovative in the field of the atomic bomb. The success of France's first atomic bomb was endogenous in terms of the acquisition of fissile material, the choice of the technology roadmap adopted, and research in related technologies. The information and technical assistance provided by the United States as an ally was not ignored, but its recognition does not undermine this endogenous nature.

References

Adamson, Matthew. 2005. "Commissariat of the Atom: The Expansion of the French Nuclear Complex, 1945–1960." PhD diss., Indiana University.

Ailleret, Charles. 2016. "Le tir." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Amiard, Jean-Claude. 2022. *Le désarmement et le démantèlement dans le domaine nucléaire*. Perth: ISTE Group.

Billaud, Pierre. 2016a. "Gerboise Bleue." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Billaud, Pierre. 2016b. "La DAM, premiers développements." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Billaud, Pierre, ed. 2016c. *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*. Paris: L'Harmattan.

Billaud, Pierre. 2016d. "La mission «AURORE» aux U.S.A." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Billaud, Pierre. 2016e. "Il y a cinquante ans!" In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Billaud, Pierre. 2016f. "Rappels sur les essais au Sahara." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Blanc, Jacques. 2008. "Les mines d'uranium et leurs mineurs français: une belle aventure." *Annales des Mines: Réalités industrielles,* no. 3, 35–43.

Bonnet, M. P. 2000. *Premiers travaux sur l'arme nucléaire: la section atomique de la DEFA jusqu'à son rattachement au Commissariat à l'énergie atomique au 1er janvier 1960*. Tome 13 of *Comité pour l'Histoire de l'Armement Terrestre (période 1945–1975)*. Paris: Centre des hautes études de l'armement, CHARME.

Bossière, C.-G. 1948a. "La pacifique pile atomique de Châtillon garde ses secrets." *Le Monde*, le 18 décembre 1948.

Bossière, C.-G. 1948b. "La pile atomique de chatillon se conduit d'un doigt." *Le Monde*, le 22 décembre 1948.

Bossière, C.-G. 1948c. "La première pile atomique française fonctionne depuis mercredi." *Le Monde*, le 17 décembre 1948.

Chevallier, Jacques. 2016. "Histoire de la DAM." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Cooper, Austin R. 2022. "Saharan Fallout: French Explosions in Algeria and the Politics of Nuclear Risk during African Decolonization (1960–66)." PhD diss., University of Pennsylvania.

Coulomb, R., M. Goldstein, and M. Le Mercier. 1958. "L'uranium dans quelques granites français. " *Geochimica et Cosmo chimica Acta* 15 (1–2): 10–17.

Duval, Marcel. 1989. "Élaboration et développement du concept français de dissuasion." In *Relations internationales*, no. 59, 371–383.

Duval, Marcel, and Dominique Mongin. 1993. *Histoire des forces nucléaires françaises depuis 1945*. Paris: Presses Universitaires de France.

Ferrand, Jean-Pierre. 2016. "Genèse de la DAM." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Gowing, Margaret. 1988. *Policy Making*. Vol. 1 of *Independence and Deterrence Britain and Atomic Energy, 1945–1952*. London: The Macmillan Press.

Jamet, Pierre. 2016. "Ma participation à Gerboise Bleue." In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Jurgensen, Céline, and Dominique Mongin. 2018. *Résistance et Dissuasion: Des origines du programme nucléaire français à nos jours*. Paris: Odile Jacob.

Le Baut, Yves. 1989. "Les essais nucléaires français de 1966 à 1974." *Relations internationales*, no. 59, 359–370.

Le Baut, Yves. 1996. *Les essais nucléaires français*. Paris: Bruylant.

Lenoble, A. 1955. "Prospection et recherche de l'uranium." In *Centenaire de l'industrie minérale*, 113, cited by Rapport de CEA, no. 1247, le mars 1959.

Liu, Jifeng 刘戟锋, Liu Yanqiong 刘艳琼, and Xie Haiyan 谢海燕. 2004. *Liangdanyixing gongcheng yu dakexue* 两弹一星工程与大科学 [The Project of "Two Bombs, One Satellite": A Model of the Big Science]. Jinan: Shandong Education Press.

Mongin, Dominique. 1989. "Forces armées et genèse de l'armement nucléaire français." *Relations internationales*, no. 59, 301–315.

Mongin, Dominique. 1997. *La bombe atomique française 1945–1958*. Bruxelles: LGDJ/Bruylant (epub version from the *Bibliothèque nationale de France*, read by Adobe Digital Editions 4.5).

Mongin, Dominique, and William Delahaye. 2020. *La Direction des Applications Militaires (CEA/DAM) au cœur de la dissuasion nucléaire française. De l'ère des pionniers au programme Simulation*. CEA/DAM.

Pelopidas, Benoît, and Sébastien Philippe. 2021. "Unfit for Purpose: Reassessing the Development and Deployment of French Nuclear Weapons (1956–1974)." *Cold War History* 21 (3): 243–260.

Pinault, Michel. 2000. *Frédéric Joliot-Curie*. Paris: Odile Jacob.

Pô, Jean-Damien. 2001. *Les Moyens de la Puissance: les activités militaires du CEA (1945–2000)*. Paris: Ellipses Edition Marketing S. A.

Schwerer, Antoine. 2016. "Auprès de ma Bombe. In *La grande aventure du nucléaire militaire français*: *Des acteurs témoignent*, edited by Pierre Billaud. Paris: L'Harmattan.

Skogmar, Gunnar. 1993. *Nuclear Triangle: Relations between the United States, Great Britain, and France in the Atomic Energy Field, 1939–1950*. Copenhague: Copenhagen Political Studies Press.

Touret, Jacques. 2005. "Un grand témoin et acteur de l'«Age d'Or» du CEA." *ABC MINES*, no. 26. https://annales.org/archives/x/sarcia.html.

Vaïsse, Maurice. 1992. "Le choix atomique de la France (1945–1958)." *Vingtième Siècle, revue d'histoire*, no. 36, 21–30.

Yao, Baihui 姚百慧. 2009. "Meiguo dui Faguo hezhengce yanban lunggang (1945–1973) " 美国对

法国核政策演变论纲（1945～1973） [An Outline of the Evolution of US Nuclear Policy toward France (1945–1973)]. *Shoudu Shifan Daxue xuebao (shehui kexue ban)* 首都师范大学学报（社会科学版） [Journal of Capital Normal University (Social Sciences Edition)], no. 2, 45–50.