Military Applications Division (DAM)

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The Military Applications Division (CEA/DAM) - a key player in developing France's nuclear deterrent

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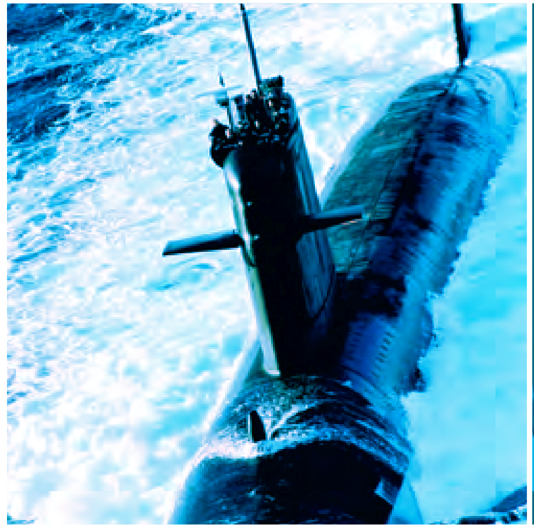
From the pioneers of nuclear physics to the Simulation Programme



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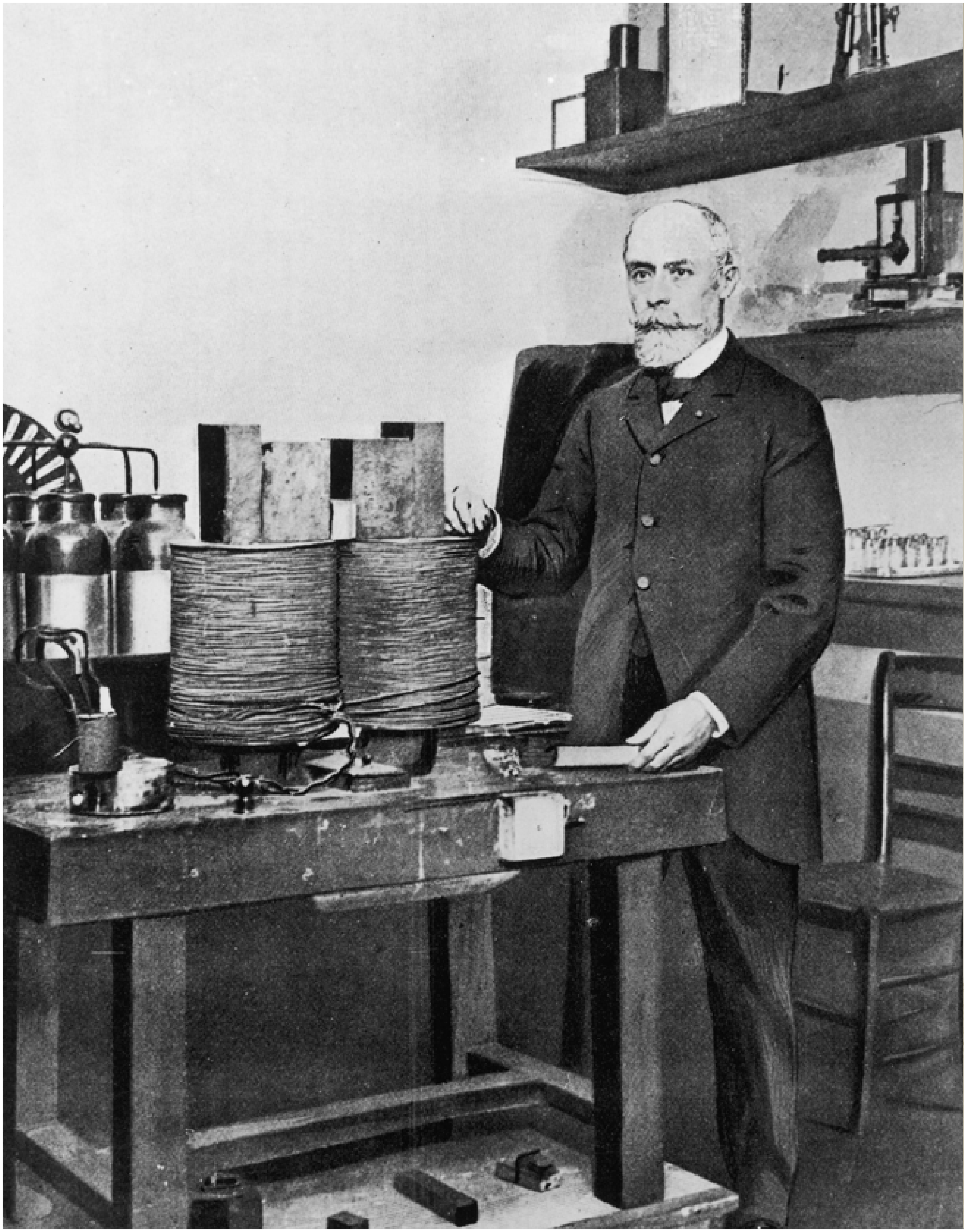


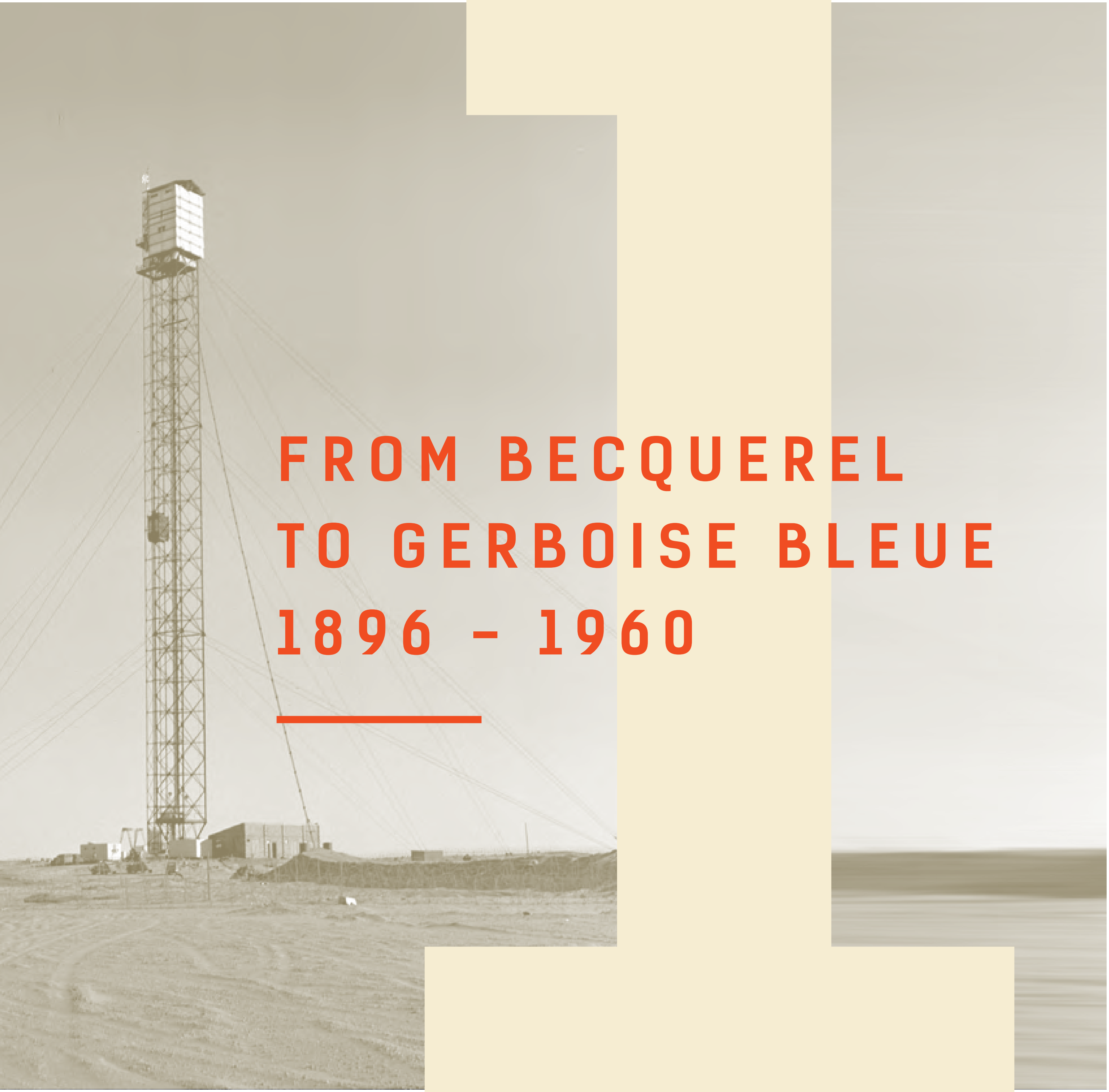

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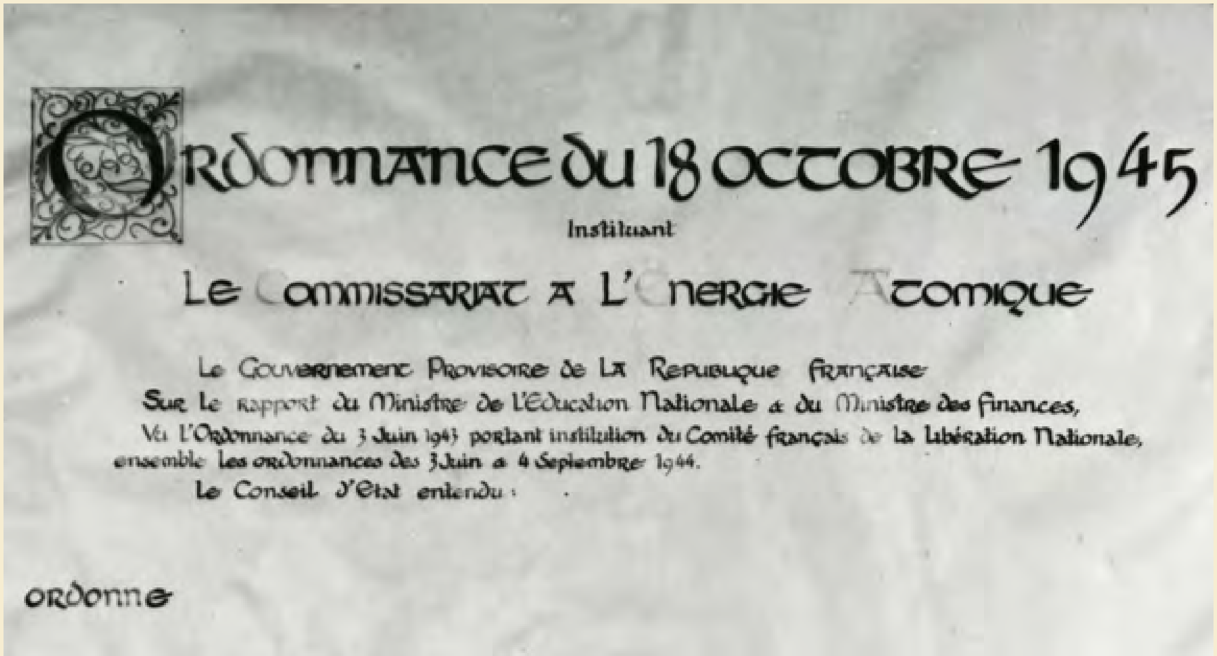
FROM BECQUEREL TO GERBOISE BLEUE 1896 – 1960

In this first chapter, we will focus on the early days of nuclear energy in France. We will show how, at international level, teams of French scientists were at the forefront of nuclear physics from the very beginning. Over a period of less than fifty years, they made a series of major breakthroughs. French scientists discovered the phenomenon of natural radioactivity at the turn of the century, followed, in the mid-1930s, by the discovery of artificial radioactivity, and then went on to register secret patents just before World War II broke out. One of these patents already looked ahead to the possibility of making an atomic weapon.

World War II put a brake on French pioneering research, but it did not stop it completely. Indeed, a small team of nuclear physicists belonging to the Free French Forces (*France Libre*) pursued these studies in secret, first in Great Britain and then in North America. In so doing, they also carried on the spirit of the French Resistance. After the war, France was the first nation in the world to set up a civil organization to lead research on civil and military applications of atomic power. The CEA (the French Atomic Energy Commission) was created in October 1945.

Above all, the priority was to rebuild the nation, based on a particularly effective tool: the five-year plan. In 1952, the first five-year plan relative to nuclear energy set out the objectives and enable the scientific and industrial drive that would give France access to nuclear power.


Ordonnance du 18 octobre 1945

instituant

Le Commissariat à l'Energie Atomique

Le Gouvernement Provisoire de la République Française

Sur le rapport du Ministre de l'Education Nationale et du Ministre des Finances,

Vu l'Ordonnance du 3 Juin 1943 portant institution du Comité français de la Libération Nationale, ensemble les ordonnances des 3 Juin et 4 Septembre 1944.

Le Conseil d'Etat entendu :

ordonne

Just two years later, a new key development took place, with the political decision to launch a French nuclear defence Programme. This decision-making process coincided with progress in scientific and industrial research being carried out in France. It illustrates the political will to give France a nuclear arsenal (nuclear weapons and nuclear-powered submarines), based on the premise that France would not unilaterally accept to abandon the development of a weapon that other World Powers possessed.

This political decision was backed by immediate funding for developing the "new weapon", together with a series of common protocols and joint committees set up to ensure coordination between the Armed Forces and the CEA's Military Applications Division (DAM). While the DAM was tasked to design and manufacture an experimental bomb, it was the Armed Forces' job to plan and organize the logistics for nuclear tests in the field. Thanks to such coordination, the first French nuclear test was successfully carried out on 13 February 1960.

1896

Radiation emitted by uranium salts discovered by French physicist **Henri Becquerel**

1898

Radium and polonium discovered by French physicists **Pierre and Marie Curie**

1903

Nobel Prize for Physics awarded to **Henri Becquerel** and to **Pierre and Marie Curie** for their work on natural radioactivity

1911

Nobel Prize for Chemistry awarded to **Marie Curie** for her work on radium and polonium. That same year, she set up the *Institut du Radium*

1934

Artificial radioactivity discovered by the physicists **Irène Curie**, Pierre and Marie's daughter, and **Frédéric Joliot**; they received the Nobel Prize for Chemistry the following year, for their research on this subject

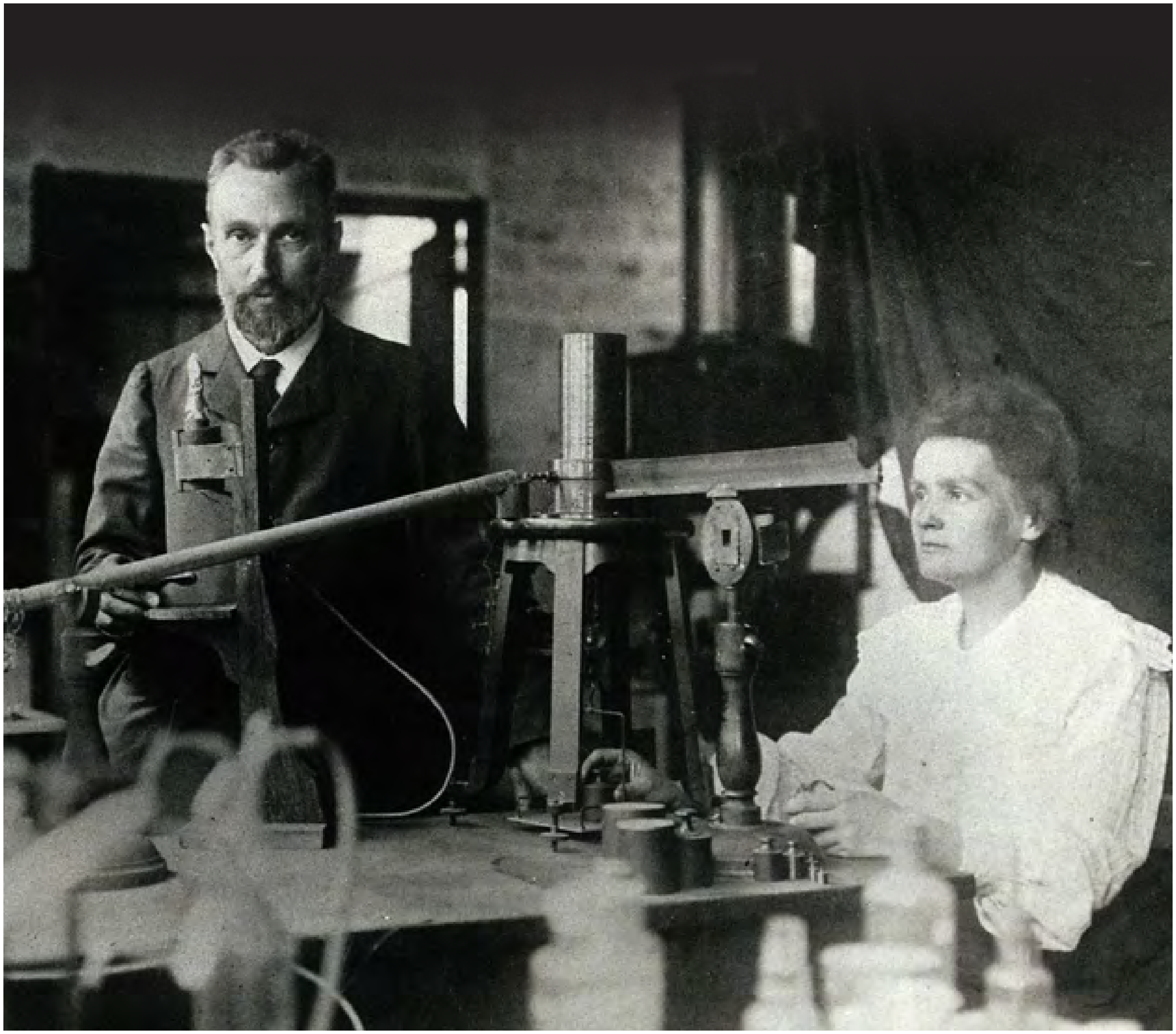
1939

Three secret patents registered by **Frédéric Joliot**'s team at the *Collège de France*

1945

Creation of the **French Atomic Energy Commission** (*Commissariat à l'Énergie Atomique, CEA*) by **General de Gaulle**

Pierre and Marie Curie
in their laboratory, 1898



1946

Frédéric Joliot was appointed High Commissioner for Atomic Energy and **Raoul Dautry** became Chairman reporting to the Government

1948

ZOE, France's first experimental reactor, went critical

1951

Francis Perrin took over from Frédéric Joliot, and **Pierre Guillaumat** from Raoul Dautry

1952

Félix Gaillard presented the **first five-year plan** relative to nuclear energy

1954

Pierre Mendès France launched the decision-making process for nuclear armament, which included **setting up the *Bureau d'Études Générales* (BEG, the General Studies Office)**, the precursor of the DAM

1955

Albert Buchalet was appointed as Director of the BEG

First Memorandum of Understanding signed between the Armed Forces and the CEA (1955-1957), together with the Plan for the development of military applications of atomic energy

Creation of two CEA Centres: Bruyères-le-Châtel, known as "BIII", and **Vaujours**, a former Central powder laboratory 1956

1956

Second Memorandum of Understanding between the Armed Forces and the CEA (1957-1961)

1957

Second five-year plan relative to nuclear energy

Creation of two more CEA Centres: Moronvilliers, annex to the Vaujours Centre, **and Valduc**, annex to the BIII up to 1961

1958

The CEA's Military Applications Division (DAM) was set up

Decision made by **Félix Gaillard** aimed at enabling France to prepare to **carry out, on orders, a nuclear test in the first quarter of 1960**

General de Gaulle confirmed Félix Gaillard's decision

1959

The Limeil Centre was attached to CEA/DAM

1960

France's first experimental nuclear bomb was detonated in Reggane (Sahara Desert in Algeria), under General de Gaulle's presidency, on 13 February

↗ **Irène and Frédéric Joliot-Curie**
in their laboratory, 1934

EARLY SCIENTIFIC DISCOVERIES

Since the end of the nineteenth century, France had played a leading role in the discovery of atomic energy. The physicist, **Henri Becquerel**, discovered radiation emitted from uranium salts in 1896. This was a major breakthrough because it demonstrated the phenomenon of natural radioactivity. Two years later, radium and polonium were discovered by **Pierre and Marie Curie**.

In 1903, these three physicists received the Nobel Prize for Physics for their pioneering work on natural radioactivity. In 1911, the Nobel Prize in Chemistry was awarded to Marie Curie for her research on radium and polonium. The same year, she founded the *Institut du Radium*, to train radiology nurses who were to care for wounded soldiers during the First World War.

In 1934, the French physicists **Irène Curie**, daughter of Pierre and Marie Curie, and her husband **Frédéric Joliot** discovered artificial radioactivity. A year later, they received the Nobel Prize for Chemistry for their research. In December 1938, two German chemists, Otto Hahn and Fritz Strassmann, described the chemical aspects of fission. A month later, the physical principle of uranium nucleus fission was demonstrated first in Scandinavia, to where the Austrian physicists Otto Frisch and Lise Meitner had emigrated, and then by Frédéric Joliot.

All these fundamental scientific advances were then taken up by the military, especially since another world war seemed imminent. Nonetheless, at the beginning of 1939, the traditional international exchanges between scientists went ahead. Leo Szilard, a Hungarian physicist who had fled to the United States, was the first, in a letter, to warn his fellow physicists about the major consequences of the on chain reactions.

To begin with, Frédéric Joliot was surprised and disagreed with the content of this letter. Thus, in March 1939, together with his colleagues at the *Collège de France*, **Hans Halban** and **Lew Kowarski**, he published a paper on the discovery of secondary neutrons. A month later, they calculated that over three neutrons are produced per fission reaction (in fact, there are 2.5).

As of May 1939, Joliot's team agreed to break with the policy of sharing research results universally practiced up until then, and began to implement a secrecy policy, even going so far as registering patents for their inventions. This new policy was decided partly due to concerns over intellectual property rights in view of future industrial applications and partly because of the strategic nature of the team's discoveries.

Joliot's team had filed three secret patents by May 1939, one of which, on the "development of explosive charges", considered the use of an explosive nuclear reaction, with various applications: mining, public works, and... warheads. Although it is still far from being a design for an atomic bomb, this patent already mentions the possibility to reach the critical stage, discovered in 1939 by French physicist **Francis Perrin**, as well as neutron initiation and the chain reaction.

RÉPUBLIQUE FRANÇAISE

MINISTÈRE
DE L'INDUSTRIE ET DU COMMERCE

SERVICE
de la PROPRIÉTÉ INDUSTRIELLE

BREVET D'INVENTION

Gr. 14. — Cl. 3.

N° 971.324

Perfectionnements aux charges explosives.

CAISSE NATIONALE DE LA RECHERCHE SCIENTI~~FIQUE résidant en France~~ (Seine).

Demandé le 4 mai 1939, à 15h 35m, à Paris.
Délivré le 12 juillet 1950. — Publié le 16 janvier 1951.

(Brevet d'invention dont la délivrance a été ajournée en exécution de l'article 11, § 7, de la loi du 5 juillet 1844 modifiée par la loi du 7 avril 1902.)

On sait que l'absorption d'un neutron par un noyau d'uranium peut provoquer la rupture de ce dernier avec dégagement d'énergie et émission de nouveaux neutrons en nombre en moyenne supérieur à l'unité. Parmi les neutrons ainsi émis, un certain nombre peuvent à leur tour provoquer sur des noyaux d'uranium, de nouvelles ruptures, et les ruptures de noyaux d'uranium pourront ainsi aller en croissant suivant une progression géométrique, avec dégagement de quantités extrêmement considérables d'énergie. Ces chaînes de ruptures successives peuvent se ramifier d'une manière illimitée, et la réaction peut devenir explosive.

On a cherché, conformément à la présente invention, à rendre pratiquement utilisable cette réaction explosive, non seulement pour des travaux de mine et pour des travaux publics, mais encore pour la constitution d'engins de guerre, et d'une manière très générale dans tous les cas où une force explosive est nécessaire.

Or, pour rendre cette utilisation pratique, il faut se reporter à la notion de masse ou en général de conditions critiques dont il a déjà été fait mention dans la demande de brevet français du 1er mai 1939 pour « Dispositif de production d'énergie ».

Il existe en effet, toutes choses égales d'ailleurs, une valeur critique de la masse d'uranium au-dessous de laquelle la ramification des chaînes cesse d'être illimitée. Et l'on a déjà indiqué dans cette demande de brevet que l'on pouvait, avec les données actuelles de la science, estimer, par des expériences progressives, la valeur de la masse critique.

On peut aussi évaluer cette masse critique M pour un composé ou un mélange homogène d'uranium (ne contenant pas d'hydrogène) en utilisant la formule suivante, valable pour une masse sphérique :

$$M = \frac{4}{3} \times \pi^4 \left[3\,D\,(n\,P - A) \right]^{-\frac{3}{2}}$$

dans laquelle :

D est la somme, pour tous les corps simples présents dans la masse, des produits de la concentration (en nombre d'atomes par cm³) par la section efficace des noyaux pour la diffusion des neutrons rapides,

A est la somme analogue, dans laquelle les sections efficaces de diffusion sont remplacées par les sections efficaces d'absorption,

P est le produit de la concentration de l'uranium (en nombre d'atomes par cm³) par la section efficace, pour le phénomène de partition, du noyau d'uranium vis-à-vis des neutrons rapides,

n. est le nombre moyen de neutrons émis lors d'une partition nucléaire de l'uranium.

Cette formule donne, à titre d'exemple, une masse critique de quelques dizaines de tonnes pour de l'oxyde d'uranium en poudre; et de quelques tonnes pour de l'uranium métallique.

On a montré également, dans la demande de brevet français précitée, comment cette masse critique pouvait être diminuée : soit en disposant autour de la masse des corps diffusants, (fer, plomb ou autres) en couche plus ou moins épaisse, et formant par exemple une enveloppe complète ou partielle autour de la masse (une enveloppe en fer de quelques dizaines de centimètres d'épaisseur réduisant par exemple la masse critique au tiers environ de sa valeur dans le cas de l'oxyde d'uranium en poudre); soit en accroissant la densité de la substance qui constitue la masse (la masse critique étant proportionnelle à l'inverse du carré de la densité).

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Prix du fascicule : 25 francs.

FRENCH ATOMIC PHYSICISTS IN THE RESISTANCE UNDER THE NAZI OCCUPATION

The patents registered by Joliot's team at the *Collège de France* reveal just how much progress had been made in French research on the civil and military applications of atomic energy. Since the outbreak of war, the focus had been on energy generation and explosive devices.

In the Autumn of 1939, the Minister of Armaments, **Raoul Dautry**, gave his full support to the studies carried out by **Frédéric Joliot**. The latter gave priority to the supply of strategic materials, i.e. uranium oxide to the fuel and heavy water, then thought of as the best neutron-moderator. By May 1938, a partnership had been set up with a Belgian company, the *Union Minière du Haut-Katanga* (Mining Union of Upper Katanga). This led to the delivery of 8 tonnes of uranium oxide from the Congo. No other laboratory in the world then held such a quantity at the time.

Joliot's team at the Collège de France
From left to right: Frédéric Joliot-Curie, Hans Halban and Lew Kowarski playing themselves in French/ Norwegian film "Operation Swallow: The Battle for Heavy Water", directed by Jean Dreville and Titus Vibe-Muller, in 1947

République Française

Présidence du Conseil

Paris, le 26 février 1940

ORDRE DE MISSION

Monsieur Jacques ALLIER est habilité par M. le Président du Conseil à traiter avec les détenteurs de la matière faisant l'objet de sa mission pour assurer au Gouvernement français la disposition des quantités les plus importantes possibles.

Il est habilité à procéder à un achat ferme immédiat ou, le cas échéant, à donner aux détenteurs de la matière la garantie du Gouvernement français dans le cas où un dépôt en France pourrait être envisagé.

M. Jacques ALLIER est expressément déchargé du soin d'assurer la matière, qu'il acheminera ou fera acheminer aux risques et périls du Gouvernement français.

Toutes autorités diplomatiques, consulaires et militaires sont tenues de prêter en toutes circonstances à M. Jacques Allier les concours nécessaires à l'accomplissement de sa mission.

Le Président Du Conseil,
Ministre de la défense Nationale et de la Guerre.

Sd. Daladier

Ordre de mission de Jacques Allier en Norvège pour l'achat d'eau lourde.

16 juin 1940

Ordre

Messieurs Halban et Kowarsky accompagnés de Mesdames Halban et Kowarsky et de deux enfants en bas âge monteront à bord du vapeur Broompark à Bassens (Gironde). Ils sont confiés à Monsieur le comte de Suffolk et Berkshire, afin de poursuivre en Angleterre les recherches entreprises au Collège de France, et sur lesquelles sera observé un secret absolu.

Messieurs Halban et Kowarsky se présenteront à Londres à la mission ~~française~~ (colonel Mayer), 2 Dean Stanley Street, Westminster House.

MINISTÈRE DE L'ARMEMENT

Pour le Ministre et par son ordre
Pour le Secrétaire Général des Fabrications
Le chef du cabinet

Ordre de mission de Halban et Kowarski pour l'Angleterre.

In February 1940, by orders of the President of the Council and Minister of National Defence, **Edouard Daladier**, a secret mission was sent to Norway to collect 185 litters of heavy water, the world's entire stock, made available to France by the Norsk-Hydro Company. **Jacques Allier**, a banker and an officer in the *Service des Poudres* (Explosive Department) who was seconded by the *Deuxième Bureau*, the French military intelligence service, was assigned to lead this mission, accompanied by a handful of French secret agents. They got the stock before the Nazis, who also wanted it.

On 16 June 1940, right before France surrendered, **Raoul Dautry** asked **Hans Halban** and **Lew Kowarski** to travel to London with the twenty-six drums of heavy water so that the work started in France could be pursued in Great Britain. This was the first international cooperation in nuclear physics, and, above all, it was one of the first acts of the Resistance within the French government just before **General de Gaulle's** call for resistance on 18 June.

Up until June 1940, France had led the race in research on chain reactions, only to find itself sidelined in the American studies, even though some degree of continuity was provided by the five French scientists seconded by the Free France (*France Libre*). Hans Halban and Lew Kowarski both worked primarily on a heavy-water reactor. **Pierre Auger** joined the Physics department at the laboratory in Montreal, while **Jules Guéron** worked in the Chemistry department. **Bertrand Goldschmidt** specialized in plutonium and its extraction.

For personal reasons, **Frédéric Joliot** decided to stay in France during the war, but refused to collaborate with the Nazi occupiers and the Vichy regime. In 1941, he joined the *Front National*, the Communist-inspired resistance movement.

↑ **Edouard Daladier**
1940

↑ **Raoul Dautry**
1940

"(...) You ask me about our stance regarding the fact that the atomic bomb has been developed and that the Americans, British and Canadians are keeping it for themselves. I would remind you that, to begin with, it was partly developed by French scientists. As you know, when war broke out, our scientists, Mr. Joliot-Curie and others had done the groundwork. Thereafter, they were unable to pursue their research due to the tragic circumstances of the war. However, what they succeeded in doing and what the French Government, to which I had the honor of belonging in 1940, managed to give the Allies the means that they had available, was not without its use in their research. (...)"

Press conference given by General de Gaulle, 12 October 1945

SETTING UP THE CEA

Although **General de Gaulle** was shocked by the Hiroshima explosion, this was not the first time he had heard about the atomic bomb; he had been informed of it a year earlier. During a visit to Canada in July 1944, as Head of the Provisional Government of France, he learned the progress on the Manhattan Project from the team of French nuclear physicists, more specifically from **Jules Guéron**.

From that point on, he realized how vital it was to resume the research that had been interrupted by the war. Having become Minister for Reconstruction, **Raoul Dautry** relaunched research in March 1945, thereby emphasizing the role that nuclear energy was expected to play in reconstructing the country. On 16 October, General de Gaulle asked **René Cassin**, Vice-President of the Council of State, to speed up the procedure to set up the French Atomic Energy Commission (*Commissariat à l'Énergie Atomique*, CEA).

Two days later, the CEA was founded by the Order of 18 October 1945. In its first article, it states that the new body was tasked with conducting scientific and technical research "*with a view to developing the use of atomic energy in various fields of science, industry and national defence*". Just two months after Hiroshima, military applications were already very clearly being considered.

The CEA was the first civil organization in the field of nuclear energy to be established anywhere in the world. It officially started operating in January 1946. Moreover, and this will become its main strength, the CEA was administratively and financially independent, enabling it to be close to the government and yet have significant freedom on the research carried out.

Two men were appointed to govern the CEA, the High Commissioner for Atomic Energy, **Frédéric Joliot**, and the Chairman reporting directly to the Government, **Raoul Dautry**. The former was in charge of scientific research, while the latter was responsible for its administrative and financial management.

While the continuity in terms of the scientific and political players involved (both pre-war and post-war) cannot be stressed enough, it should be mentioned that the governance was pre-empted by Joliot, given the scale of his international scientific reputation since the 1930s.

The fact that Joliot had remained in France during the war had done nothing to diminish his fame, although we could imagine how different things might have been for France if he had gone to Great Britain or the United States to work with the Resistance there. In any case, he had refused to collaborate with the Nazis and the Vichy regime. But as the Cold War progressed, it was his Communist sympathies that would tarnish his credibility.

"(...) the authorities in France must ensure that France is able to act independently (...) France needs a system of defence, one that is proportional to our resources, and associated with that of our allies, while remaining autonomous and balanced. France, also, must be a Nuclear Power. It is for this reason that I founded the High Commission [CEA] in 1945 (...)".

Press conference given by General de Gaulle, 7 April 1954

The team involved in building the ZOE reactor in Châtillon, 1948
The photograph shows Bertrand Goldschmidt, Lew Kowarski and Frédéric Joliot-Curie in the front row, seated second, fourth and fifth from the left

The CEA's Scientific Committee in 1946
From left to right; in the forefront: Pierre Auger, Irène and Frédéric Joliot-Curie, Francis Perrin, Lew Kowarski; In the back front: Bertrand Goldschmidt, Pierre Biquard, Léon Denivelle.

Inauguration of the ZOE reactor
1948

THE PLAN TO DEVELOP FRANCE'S NUCLEAR INDUSTRY

Once the CEA had been set up, it was important to acquire premises in order to start work. In 1946, the CEA acquired the Fort de Châtillon, near Paris, which became its first research centre, as well as part of the Bouchet powder factory, where uranium was initially to be processed and refined. General **Dassault**, the brother of the aeronautics manufacturer, who was the military representative on France's Atomic Energy Committee, played a decisive role in these acquisitions. The following year, the Saclay Research Centre opened with the help of **Irène Joliot**.

Starting in 1948, a whole new dynamic emerged, in two directions, starting with the discovery of the first deposit of pitchblende in France, in the Limousin region. Second, the experimental atomic pile (or reactor) at Châtillon, named "ZOE", standing for *Zéro-Oxyde d'uranium-Eau lourde* (Zero-power-uranium Oxide fuel-heavy water), reached criticality. A year later, in 1949, the first milligram of plutonium from the ZOE reactor was isolated.

However, the first real factor that paved the way for the future nuclear defence programme was the launch of a five-year plan relative to nuclear energy. This is all the more important in that it also laid the foundations for the Military Planning Act passed since the 1960s. **Félix Gaillard**, former head of **Jean Monnet**'s Cabinet at the *Commissariat Général au Plan* (General Plan Commission), was the brain behind this nuclear energy plan. Then a young member of Parliament, Gaillard had been aware of nuclear issues since 1949 thanks to **Bertrand Goldschmidt**, before becoming Minister of State to the Council President in 1951.

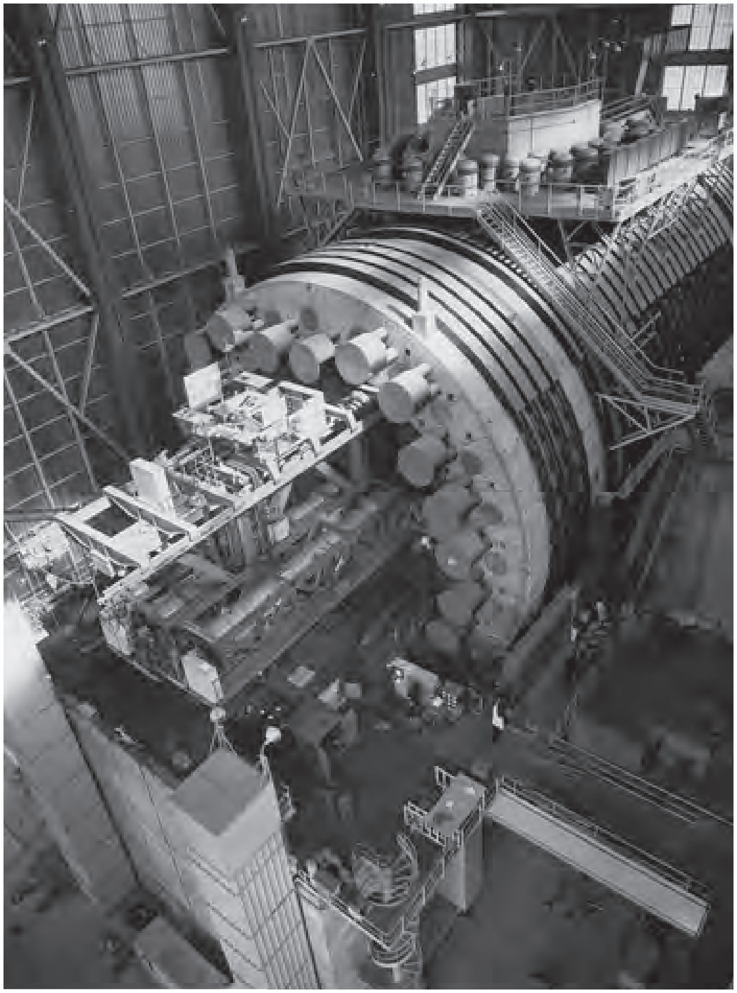
The first five-year plan relative to nuclear energy (1952-1957) was passed in July 1952. The President of the Council of Ministers, **Antoine Pinay**, had given it his full support. With a budget of 38 billion French francs, it provided for the construction of two graphite-moderated nuclear reactors.

This confirmed the decision to develop the GCR (natural uranium graphite-moderated gas-cooled reactor) system, even if this decision provoked debate within the CEA between those who favored heavy water and those who preferred graphite-gas. The first three G1 (G for graphite), G2 and G3 reactors were built at the Marcoule site. In 1956, the G1 reactor reached criticality, leading to production of 10 kilos of plutonium a year.

In 1952, there was no specific policy regarding possible military applications, because it was still too soon to start work on applications for national defence (a common R&D core was required first). However, this plan enabled France to produce significant quantities of fissile material in a relatively short period. At the same time, those who drew up the plan also had it in mind to boost the country's electricity supply, which is why G2 and G3 were connected to the electricity grid in 1959 and 1960 respectively.

MARCOULE

Marcoule in 1958



The G2 reactor and its vessel, ↑
viewed from the loading side

Plutonium extraction workshop ↑

G1 reaching criticality, 1956

From left to right: Charles Brune, Interior Minister-Antoine Pinay, President of the Council of Ministers-Félix Gaillard, Minister of State reporting to the President of the Council, 1952

"(...) it would be very odd, at a time when so many nations on either side of the Iron Curtain are producing weapons of mass destruction, if France were to refuse on principle to take up this option for our own national defence (...)"

Félix Gaillard's response to the amendment submitted by the French Communist Party members of Parliament, who wanted to prohibit France from manufacturing nuclear weapons, French National Assembly, 3 July 1952. The amendment was rejected by a substantial majority.

Before considering the possibilities of implementing a nuclear defence programme, hostility factors on the domestic front to developing military applications of nuclear energy in France needed to be dealt with. The main opposition to such development had its roots in the pacifist movement, voiced by the French Communist Party (PCF) in particular. Because of **Frédéric Joliot**'s close ties with the PCF, and thus his aversion to the prospect of France acquiring nuclear weapons, he was dismissed as High Commissioner in April 1950. He was replaced **Francis Perrin** in 1951.

At the same time, the CEA's new director delegated by the government (*administrateur general*), from 1951 to 1958, **Pierre Guillaumat**, was to play a decisive role in overcoming two foreign policy constraints which, had they been enforced, would have prohibited France from developing nuclear weapons:

- the ECD alert (European Community of Defence): based on the principle of non-discrimination towards the Federal Republic of Germany (which, since the end of World War II, had to explicitly renounce developing a military nuclear programme), other Member States party to the draft ECD treaty were asked to undertake not to produce more than 500 grams of plutonium per year.

- the EURATOM "alert" (draft treaty of the European Atomic Energy Community): the initial draft treaty was aimed at regulating the possibility of a Member State's nuclear programme branching off into the development of military applications, by establishing compliance checks. In practice, this meant that the Member States had to give their consent before any other Member State could embark on a programme to build an atomic bomb.

Thanks to the firm stand taken by Pierre Guillaumat in countering both these proposals, France conserved its nuclear independence. This success also enabled Guillaumat to promote the CEA's unique advantages as the organization best able to develop a nuclear defence programme: it held fissile material, as a public entity, it had administrative flexibility, and it had the human and financial resources required. Furthermore, this action was backed by politicians who were in favour of developing nuclear weapons, led first and foremost by **General de Gaulle**.

Under the government headed by **Pierre Mendès France**, formed in June 1954, a series of decisions was taken which achieved a whole new step towards an operational plan. In October 1954, France set up the High Commission for the Military Applications of Atomic Energy to coordinate the future nuclear defence programme. A month later, an Order was passed setting up the Nuclear Explosives Committee (CEN). The first of these bodies never had a meeting, but the second was to become particularly active, under the authority of General **Jean Crépin**, Permanent Secretary-General for National Defence.

"(...) these same heads of government have agreed to a treaty which, were it to be ratified, would, for the next fifty years, in other words, forever, wrench from France the ability to determine its own fate, take away its own armed forces, and block all access to nuclear weapons (...)"

Press conference given by General de Gaulle, 7 April 1954 (on the ECD treaty)

↑ **Pierre Guillaumat**

↑ **Pierre Mendès France**

In fact it was the CEN which developed a project of a nuclear device using plutonium, drawn up by Professor **Yves Rocard** for the CEA and Chief Engineer **Paul Chanson** for the Armed Forces. This plan, presented to **Pierre Mendes France** on 24 December 1954, recommended the following measures:

- to build two nuclear reactors (G2 series) able to produce 70 to 80 kilograms of plutonium per year
- to form teams of scientists and technicians under the supervision of a General Studies Office, *Bureau d'Études Générales* (BEG) attached to the CEA
- to set up a test site in the Sahara Desert
- to develop a permanent network to detect nuclear weapons testing

To accelerate progress on this project, Pierre Mendès France called an interdepartmental meeting with the key high authorities concerned with nuclear issues, held at his offices at the Foreign Ministry (he was also Minister for Foreign Affairs at the time).

At the end of this meeting, held on 26 December 1954, the President of the Council of Ministers confirmed the direction he had already decided on, with the creation of the two organizations mentioned above:

1. The decision to launch the programmes to manufacture nuclear weapons and nuclear submarines had to be taken.
2. The decision relative to nuclear weapons was to be secret.
3. The Minister for National Defence would present a draft decision to the Council of Ministers.

While the logical connection between points 2 and 3 is somewhat ambiguous (the Council of Ministers was not the appropriate forum to deal with this type of issue), no formal decision was actually taken under Mendès France, since his Cabinet collapsed in February 1955. However, the decision to set up the General Studies Office (BEG), on 29 December 1954, very clearly confirmed Mendès France's commitment to a nuclear defence programme. The BEG was tasked with designing and manufacturing a nuclear device.

This decision illustrates the level of secrecy in which the early days of what became later the CEA's Military Applications Division (DAM) have been shrouded. It was also no coincidence that Colonel **Albert Buchalet** was appointed to head the new entity. **Pierre Guillaumat** knew him from their time together in the French Resistance, working at the BCRA (the Central Bureau of Intelligence and Operations) during World War II. Here too, we see that the spirit of the Resistance was a sort of "badge of honor" for the clandestine launch of France's nuclear defence programme.

↑ **General Albert Buchalet**

↑ **Francis Perrin and Pierre Guillaumat**
as the G1 reactor at Marcoule reached criticality, 1956

← **United Nations Conference on the Peaceful Uses of Atomic Energy, 1955.**
From left to right: Félix Gaillard, Francis Perrin and Gaston Palewski

By March 1955, the BEG was fully operational. It acquired some land near Paris, in Bruyères-le-Châtel, and began moving in three months later. The purchase of this estate, which included a small castle, had been made possible by funding from the French Secret Services (SDECE), using a cover story to hide the real reason for the construction work. Scientific support for the first projects conducted by the BEG was provided by **Yves Rocard**, Professor at the *École Normale Supérieure* and member of the Atomic Energy Committee.

On the military side, many officers and engineers were convinced that developing the military uses of atomic energy was essential. Thus, the *Service des Poudres* (France's Explosives Department) had been interested in being involved since 1945. Within the Land Forces, studies had been undertaken to better understand the workings of a nuclear device and its possible effects, primarily for protection from those effects. At this time, several factors on the international scene began to impact on the debate in France. The fall of Diên Biên Phu in 1954 demonstrated that France could be isolated in certain risky situations, just as two years later, during the Suez Crisis, when the Soviet Union threatened France with a nuclear attack. In March 1954, Chief of Defence Staff General **Paul Ely** argued his view to his minister, **René Pleven**, on the importance of having a nuclear arsenal, as a factor of military strength, and now a defining feature of a World Power.

Bruyères-le-Châtel-Château du Rué, 1946

↓ **Bruyères-le-Châtel Centre (BIII),**
1959

↓ 1965

VAUJOURS

↑ 1956

↓ 1961

VALDUC

↑ 1998

↓ 1960

MORONVILLIERS

↑ 1960

↓ 1960

LIMEIL

↑ 1966

Pierre Guillaumat was perfectly well aware that an excellent understanding between the CEA and the military establishment was the key to success in France's development of a nuclear defence programme. As a result, and provided that the CEA's prerogatives were respected, the CEA's general director sought to establish close relations with the Armed Forces. A series of Memorandums of Understanding (MoU) was drawn up, setting out the policy regarding this crucial coordination between the two institutions. The first of these (1955-1957) was signed on 20 May 1955 between the Minister of State reporting to the President of the Council of Ministers, **Gaston Palewski**, the Defence Minister, General **Pierre Koenig**, and the representative of the Finance Minister, **Gilbert Jules**.

This MoU provides for the construction of a third graphite-modulated reactor, a plant for the chemical reprocessing of plutonium, and a nuclear-powered submarine. It also provided funding of 20 billion French francs from the Defence Ministry budget. On the same day, a secret decree set down the decision to implement a Plan for the development of the military applications of atomic energy, with a budget of 100 billion French francs, in other words, double the amount made available under the five-year plan relative to atomic energy of 1952. Elaborated under President of the Council **Edgar Faure**, this MoU was the result of discussions between several ministers who had been part of the Free France, and, again, the Resistance networks proved invaluable to the clandestine work embarked upon for France.

A second MoU between the Armed Forces and the CEA (1957-1961) was signed on 30 November 1956 by the Defence Minister, **Maurice Bourgès-Maunoury**, and the Minister of State reporting to the President of the Council, **Georges Guille**. It set out the division of tasks between the CEA and the Armed Forces. The CEA, under government's orders, was to produce a prototype of nuclear weapon, using enriched uranium (after demonstrating that the use of plutonium could be properly managed) and conduct experimental nuclear explosions. The military was to provide logistics support for these tests.

↑ **From left to right: Francis Perrin-Georges Guille, Minister of State reporting to the President of the Council-Pierre Guillaumat,** Saclay, 30 March 1956

In December 1956, an Armed Forces-CEA Joint Committee was formed to coordinate all Defence nuclear activities. This was the Committee for the military applications of atomic energy, chaired by the Chief of the General Staff for National Defence. During the year 1956, the Defence Minister, Bourgès-Maunoury, exerts a major influence on the evolution of the position of President **Guy Mollet**, who, although not initially in favour of France becoming a Nuclear Power, finally came round to the idea.

A year later, under Bourgès-Maunoury's Cabinet and further to a decision taken jointly by the Defence Ministry and the CEA, the Joint Armed Forces-CEA Nuclear Test Group was set up, in March 1957. The way was now open for an experimental test.

"(...) What is an atomic weapon for a nation such as France other than a defensive weapon, a reprisals weapon, a weapon of economy that our position compels us to possess so that we are not forced to seek it elsewhere, and this only in the event that the disarmament and control conferences fail to reach agreement on this essential point? (...)"

Maurice Bourgès-Maunoury, debate on EURATOM at the French National Assembly, 10 July 1956

Guy Mollet and Maurice Bourgès-Maunoury,
1957

TOWARDS THE FIRST FRENCH NUCLEAR TEST

For the CEA, the two immediate challenges were to make the experimental device and to prepare for nuclear testing. According to the Order of 1945, the CEA was the public entity tasked with designing and manufacturing the atomic bomb.

To develop the nuclear device, several stages had to be completed simultaneously, both in order to have the fissile material required and to design and manufacture the nuclear bomb:

CHEMICAL EXTRACTION OF PLUTONIUM: industrial extraction processes were developed at a pilot plant at the Fontenay-aux-Roses Centre. It was there that the first gram of plutonium was isolated, in 1954. Since the plutonium must accumulate in the irradiated uranium fuel rods used in the G1, G2 and G3 reactors, a remote-controlled plant had to be built nearby, in Marcoule, in order to handle this highly toxic material from a distance. The plant began operating in January 1958.

DESIGN AND MANUFACTURE OF THE DEVICE: the method chosen for the planned experimental test would be an implosion device. The military engineers at the *Service des Poudres* (Explosive Department) were highly-specialized in the phenomenon of implosion. There were still four problems to be resolved:

· **Theoretical nuclear physics:** meticulous care had been taken since the outset over the theoretical computations, in order to ensure a successful full-scale test. The CEA set up a Computing Centre for this purpose. It was equipped with the most cutting-edge computers, primarily for calculating the mass of the fissile material to be used in the device, specifying the chain reaction process and calculating the amount of energy produced by the explosion.

· **Experimental nuclear physics:** in this field, the CEA engineers needed more advanced knowledge of fast neutron physics. Their research focused in particular on neutron initiation. The solution provided by military engineers from the atomic physics department at the Defence Ministry's weapons design division (DEFA), who joined the DAM when it was officially set up in September 1958.

· **Metallurgy:** a very broad spectrum of studies was carried out, from pure research on plutonium metallurgy to making the core element for the device.

· **Ballistics:** this involved adapting conventional explosives technology to the required objective. Following the preliminary theoretical studies conducted by the *Service des Poudres* (Explosive Department) since 1951, the initial studies in this field could be launched.

While these studies were being carried out, it became urgent to prepare a test center in the Sahara to conduct nuclear experiments. These tests were conducted to verify the assumptions and theoretical calculations related to the workings of the explosive, the initiating neutron flux, the development of the chain reaction, the fission products and energy released, to learn how future models could be improved. It was thus the DAM's task to deploy the device at the firing test range and perform scientific measurements.

In addition, these tests would enable a certain number of measurements to be made to improve knowledge in fields such as shock waves, electromagnetic wave propagation and seismology. The tests would also enable the military to determine the effects of a nuclear explosion, primarily in order to protect themselves.

The Armed Forces were to build the Test Centre. They began looking for a site at the end of 1956 and, in July 1957 (under **Bourgès-Maunoury**'s government) they decided to use a site in Reggane, an oasis 150 kilometers south of Adrar, in the middle of the Tanezrouft Desert (Sahara of Algeria). The Saharan Centre for Military Experiments (CSEM) site was chosen for many reasons: distance from major populated areas (Colomb-Béchar was over 700 km to the north), the vast extent of the desert, the possibility of rapidly building a base for the teams (Reggane- Plateau, 15 km south of the Reggane oasis). The Armed Forces set up a central observation and fire control post in Hammoudia, 45 km southwest of the workers' living facilities; the firing range was 16 km away from the central firing post.

In February 1958, the Defence Minister set up the Joint Forces Special Weapons Command tasked with conducting that part of the nuclear test campaigns which were not under the CEA's remit. General **Charles Ailleret** was appointed to head this Command. One month earlier, a Safety Committee, headed by the High Commissioner for Atomic Energy and bringing together scientists and medical experts, had been set up to define the safety standards to be implemented to prevent any risk to the test operatives and local civilians.

Then, on 11 April 1958, President **Félix Gaillard** ordered the CEA and the Armed Forces to take the preparatory measures required to carry out, on the Government's orders, the first series of nuclear weapons test explosions in the first quarter of 1960. On 22 July as the last President of the Council of Ministers under the Fourth Republic, **General de Gaulle** ratified this decision, and "Gerboise Bleue" was tested on 13 February 1960.

← **National Military Powder Factory at Le Bouchet** (Seine-et-Oise)

← **Visit by General de Gaulle to Marcoule**, 2 August 1958

Preparations for the first test

↑ **Transporting the experimental device to the test slab**
in Moronvilliers, 1959

↓ **From left to right: MM. Médard, Cachin, Geerts, Fichou and Provost**
in Mourmelon, 1951

↓ **Jean Viard (right) during a test of a Gerboise Bleue model**
in Moronvilliers, 1959

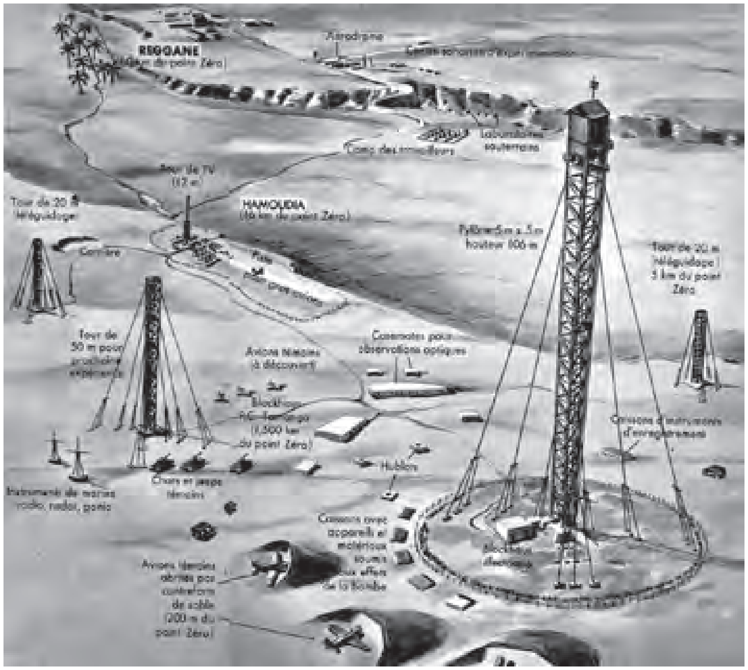
↓ Bull Gamma 30 Computer in 1962

Saharan Centre for Military Experiments (CSEM)
in Reggane

CSEM REGGANE

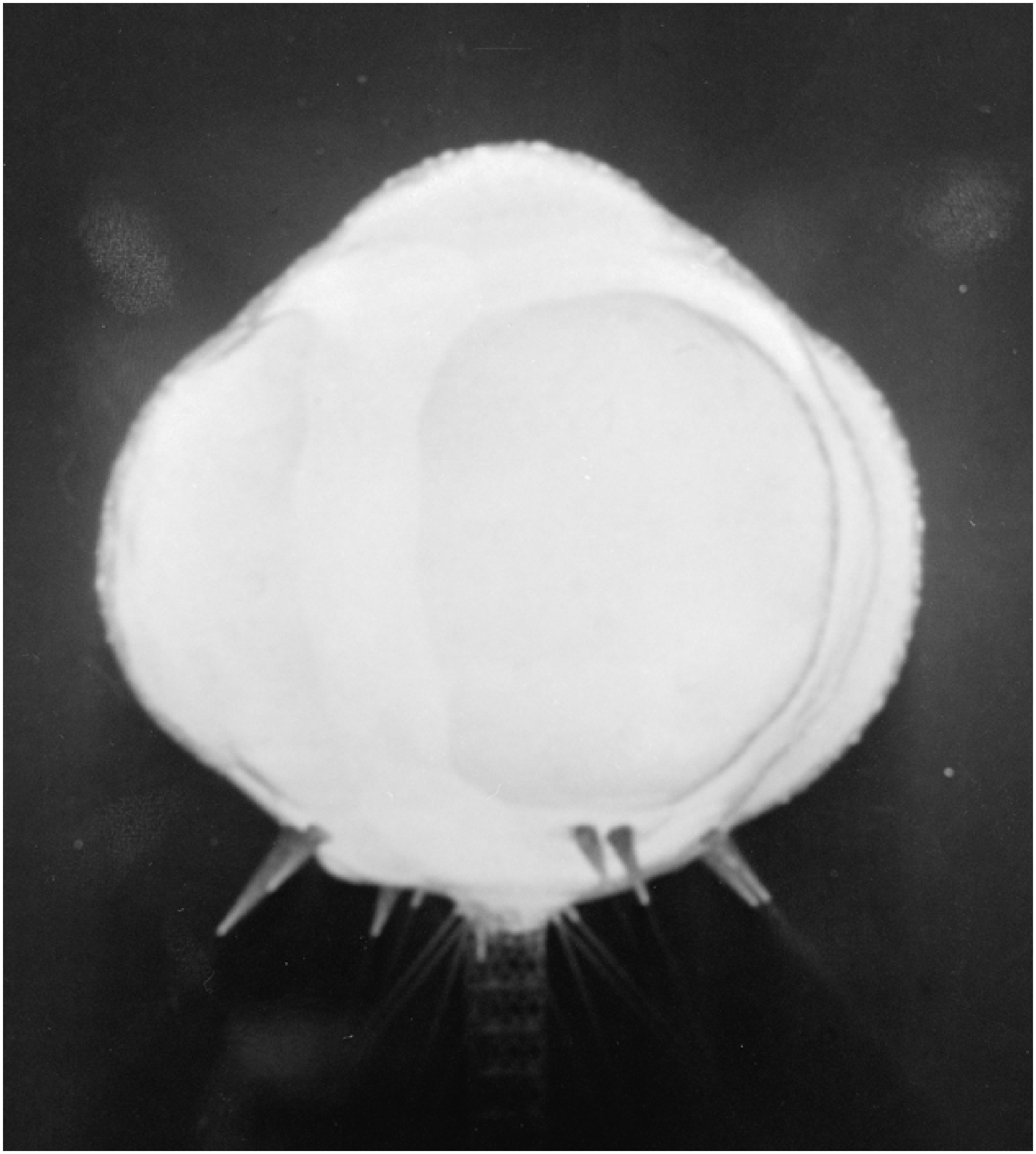
↗ Entrance to the site

↘ General Charles Ailleret



↖ Command post

↙ Site layout



↑ **Fireball produced by the explosion of Gerboise Bleue, 13 February 1960**

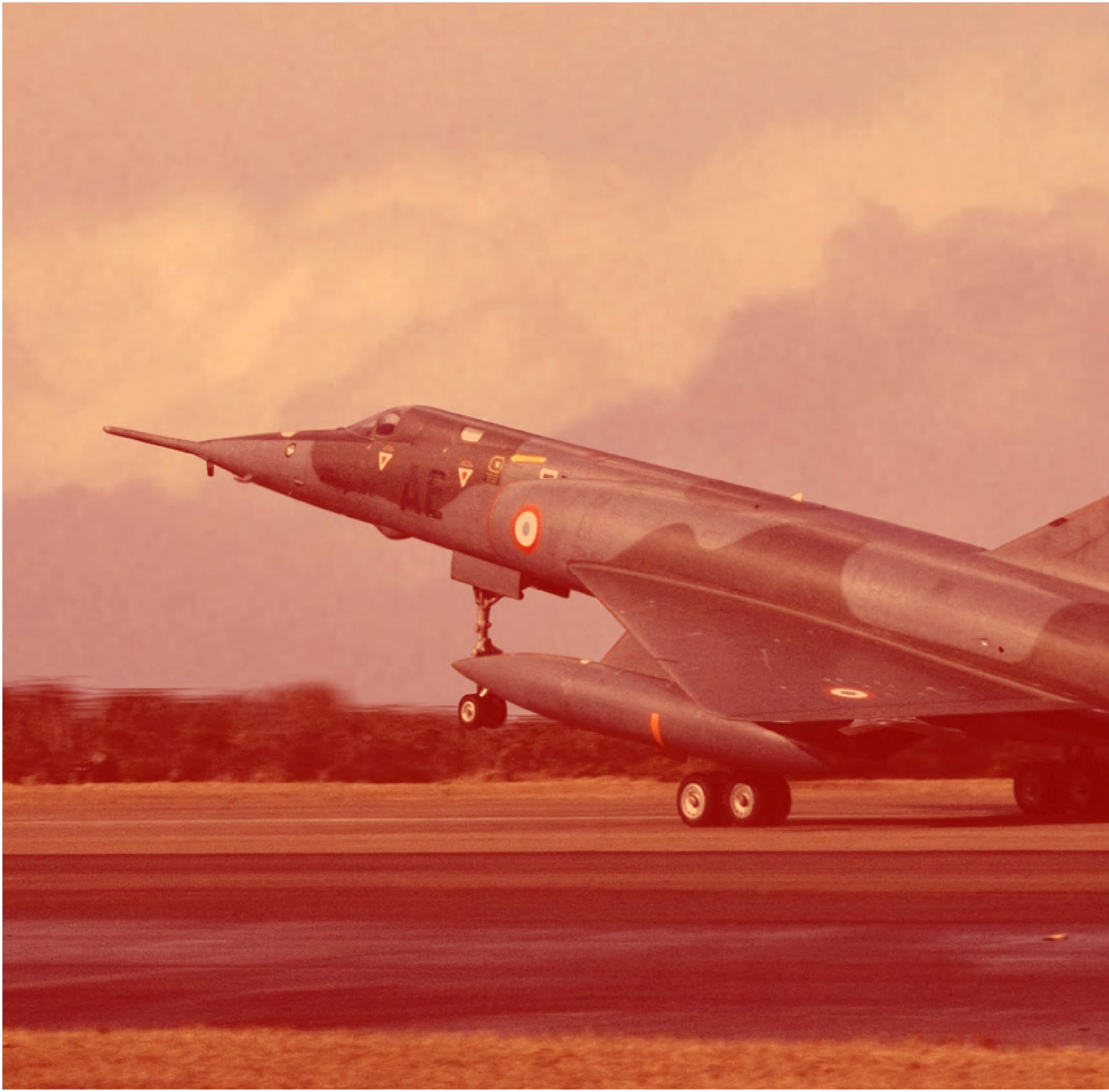
"The defence of France must be French (...)

If a nation such as France must go to war, that war must be France's war. France's military effort must be its effort. If it were any other way, our nation would be in contradiction with its foundations, with its role, with its self-esteem, with its very soul.

Of course, France defence could, if necessary, be allied to that of other nations. That is in the nature of things. But it must be our own, that France can defend itself, by itself, for itself and in its own way (...)

This implies, of course, that we must be capable of arming ourselves, over the coming years, with a force that can take action on our own account, what is commonly known as "a strike force" that can be deployed anywhere, at any time. It goes without saying that this force will be built on an atomic weapon (...)."

Speech made by President Charles de Gaulle at the military Academy, 3 November 1959



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FROM THE ATOMIC BOMB TO THERMONUCLEAR WEAPONS 1960–1968

With its first nuclear test on 13 February 1960, France demonstrated its mastery of fission technology, and thereby took its place among the World's Nuclear Powers. Subsequently, the CEA/DAM's role was to militarize nuclear weapons, i.e. ensure that they would be operational, adapting them to a given vector so that they could be transported. The Military Applications Division (DAM) is responsible not only for designing nuclear devices but also for their manufacture and through-life support.

The national R&D effort required was made all the more effective by a plan covering the lifetime of military equipment as a whole, following in the footsteps of what had made the first five-year atomic energy plans so successful.

Now that France was a Nuclear Power, it needed a strategy without further delay. France's nuclear doctrine was drawn up in the 1960s, taking inspiration from the pioneering research carried out by many general officers belonging to the three branches of the Armed Forces.

At the same time, the human, technical, real estate and financial resources allocated to the DAM were significantly increased, enabling it to fulfil the missions for which it was created.

In addition, the role of full-scale nuclear tests became key to the credibility of nuclear deterrence. Testing was, at the time, the only way to guarantee the weapons' operational reliability and safety. It was a matter of credibility, both technical and political.

During that period, one of the major challenges which the DAM had to overcome was related to thermonuclear technology. France finally mastered it in 1968, not without some difficulty. This consolidated its status as a Nuclear Power, since it meant it had (for equal mass) more powerful, more precise nuclear weapons, which could if necessary, break through enemy anti-missile defences more easily.

To **General de Gaulle**, Founder of the Fifth Republic, the development of a thermonuclear capability was also a means for France to strengthen its nuclear deterrence, and even make it irreversible.

1960

Jacques Robert took over from General Buchalet as Director of CEA's Military Applications Division

Parliament adopted the **1st Military Planning Act 1960-1964**

1961

France's last atmospheric test of a nuclear device in the Sahara was performed in Reggane on 25 April followed in November by its **first nuclear test in an underground drift** in Tan Affela Mountain, near In Ecker, in the Hoggar mountain range

Prime Minister **Michel Debré** issued a ruling on military nuclear programme procedures and created **the Armed Forces–CEA Joint Committee**

1962

Evian agreements signed, providing France with the option to pursue nuclear tests in Algeria for the next five years

CEA/DAM Ripault Centre set up

The Pacific Testing Centre (CEP) was set up

1963

French Government ruling relative to the Strike Force, which would eventually include three components: air, land and submarine; the priority was henceforth to build the first French nuclear-powered ballistic missile submarine (SSBN) and build up a strategic ground-based missiles force on the Plateau d'Albion

1964

Decree relative to the French President's authority over the **Strategic Air Forces (FAS)**, and the first FAS squadron became operational

Second Military Planning Act **(1965-1970)** adopted

Division in charge of Nuclear Test Centres **(DIRCEN)** set up

1965

Aquitaine Scientific and Technical Research Centre (CESTA) set up

Astérix, **the first French satellite**, sent into orbit by a Diamant rocket

1966

France officially **withdrew from NATO integrated military command**

Last underground nuclear test in the Hoggar Mountains, followed by the **first atmospheric nuclear test in French Polynesia**, above Mururoa atoll

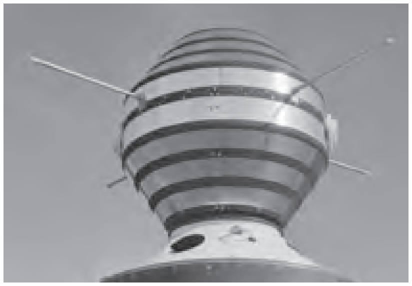
1967

First **highly enriched uranium ingot produced at Pierrelatte**

1968

France's first thermonuclear weapon tested in French Polynesia

NUCLEAR DEFENCE AND PLANNING



↑ **The first SSBN, *Le Redoutable*, launched in Cherbourg**
by General de Gaulle, 29 March 1967

↑ **Launch of the Diamant rocket carrying the Astérix satellite at Hammaguir base, 26 November 1965**

General de Gaulle's believed that the success of the development of the nuclear defence programme was dependent on budget planning. It can be seen in the subsequent definition of the five-year nuclear energy plans, which had, as we have seen, underpinned the launch of atomic energy in France.

Thus, **General de Gaulle**, the Founder of the Fifth Republic, had drawn up and adopted the Military Planning Act (LPM) which, originally, covered only specific military equipment, primarily the most significant of this equipment, i.e. nuclear weapons (since 1976, LPMs have covered the entire Defence Ministry budget).

A substantial budget investment was required of the French Parliament in order to give France a full arsenal of nuclear weapons.

The first two Military Planning Act (LPM) laid the foundations and ensured the long-term build-up of the "Strike Force", starting with the commissioning of the Strategic Air Forces (FAS) in October 1964, then equipped with *Mirage IV-A* aircraft.

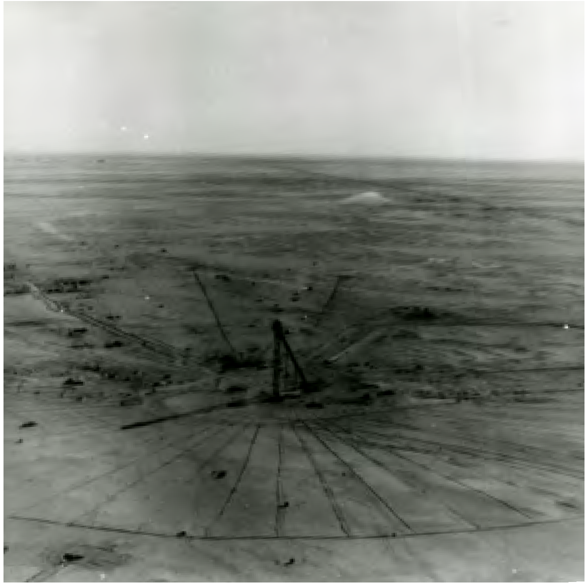
Reflecting the importance given to nuclear deterrence, at the end of General de Gaulle's presidency (1959-1969), this force accounted for 24% of the total Defence Ministry budget, and 50% of investments under that same budget. To gage exactly how significant this investment was at the time, we can compare these figures with those of the current budget, of around 10% and 20% respectively. The total cost of building up the strike force between 1960 and 1990 was an estimated 150 to 160 billion euros.

Apart from the budget allocation, the LPMs were, from the outset, significant in that the National Assembly was closely involved in decision-making relating to the military use of nuclear energy and established parliamentary debate on the role of nuclear weapons in national defence strategy.

Although the first LPM stirred up a great deal of controversy, forcing the government to invoke Article 49-3 of the French Constitution, as some members of Parliament felt that such an investment was beyond France's means. Since then, a real consensus of political opinion has developed regarding France's need for a deterrent force.

LPM	Date approved	Major weapons programmes
1960-1964	December 1960	First-generation airborne component produced *(Mirage IV-A ircraft)*; studies on ballistic missiles; construction of the first SSBN began; construction of Pierrelatte enrichment plant launched.
1965-1970	December 1964	First SSBN completed, production of the second airborne component launched (at the Plateau d'Albion) for strategic ballistic ground-based missiles; ground-based tactical missiles (*Pluton* missile) produced

General Albert Buchalet and his successor, Jacques Robert
Directors of the DAM



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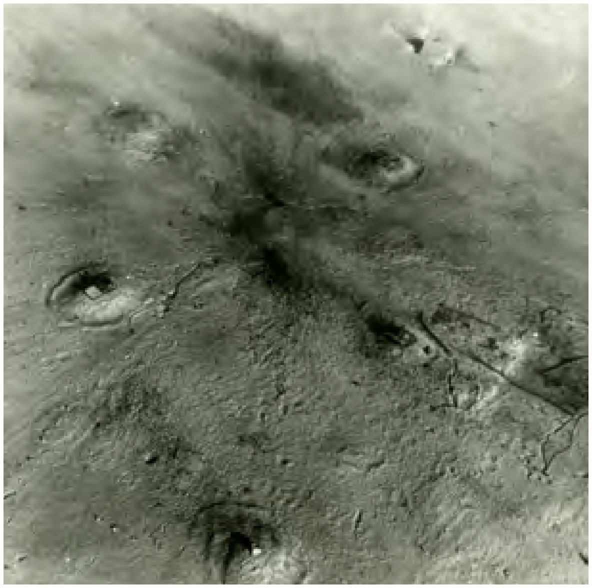


After

↑ **Gerboise Verte, last atmospheric test in Reggane**
April 1961

↖ **Oasis Military Test Center**
CEMO

THE EMERGENCE OF FRANCE'S NUCLEAR STRATEGY

Most of the time in military history, a new weapon appears before being integrated into a strategy. This was the case of nuclear weapons, used in August 1945 to put an end to World War II. Nonetheless, in France, many experts in strategy soon began to conceptualize the impact that the development of this new weapon might have.

The first Frenchman to do so was Admiral **Raoul Castex**, in a paper published in the *Revue de défense nationale*, just two months after Hiroshima. In this paper, he looks ahead to the basis of the concept of nuclear deterrence, emphasizing the point that the atomic bomb will enable a "weak nation" to deter a "strong nation" from attacking it.

"(...) Just like a strong nation, a weak nation will have atomic weapons, fewer in number perhaps, but numbers matter little given the immense power of the individual device (...)"

Admiral Raoul Castex, "Aperçus sur la bombe atomique", *Revue de défense nationale*, October 1945

It was **Pierre Gallois**, then a colonel in the French Air Force, who laid the foundations of the doctrine of nuclear deterrence in a dissertation presented at the *École Supérieure de Guerre Aérienne* (Air Force Academy) in September 1954. According to Gallois, the atomic bomb was, first and foremost, an effective weapon in "*discouraging attack*".

↑ Raoul Castex

↑ Pierre Gallois

Gallois realized at the time that the imbalance between conventional forces was too great to guarantee the defence of Western Europe by these means alone. While he acknowledged that, at that point in time, it was the USA that guaranteed the defence of Western Europe thanks to their nuclear capability, there was no guarantee that this would always be the case. Gallois believed that the future would be "atomic" and required that France should defend itself with its own means and, more specifically, nuclear weapons. His arguments echoed the very novel innovating thinking held at the time by **General de Gaulle**.

"(...) If the enemy should launch a nuclear attack, its primary target would be the allies' nuclear retaliation forces. Given the potential mobility of these retaliatory forces, the enemy could hardly destroy them unless it succeeds in attacking them all at the same time, thereby preventing the alert that would be given out to the others by a single attack. The greater the distance between the launch points or bases of the nuclear riposte forces, the less such a simultaneous attack would be possible (...)".

Colonel Pierre Gallois, dissertation presented before the *École Supérieure de Guerre Aérienne*, September 1954

In 1960, in his work entitled *Strategy for the nuclear age*, General Gallois developed the theory of "deterrence of the strong by the weak". France was to adopt this theory with even greater conviction as the United States was beginning to shift from a strategy of "massive retaliation" to one of "flexible response". He evoked the "balancing power of the atom", the need to balance the stakes involved against the risks, proportional deterrence and the impossibility of sharing the decision to use nuclear weapons.

"(...) Nuclear war will perhaps never take place and we certainly hope it never will. If that is so, it will undoubtedly be thanks to efforts we have made to build up armed forces that are fully adapted to this form of warfare. If we hold on to obsolete weapons, it will be an open invitation to the enemy to take the easy option (...)."

General André Beaufre, speaking before France's High Council of the Armed Forces, 5 November 1954

At around the same time, since the mid-1950s, **André Beaufre**, a General in the French Army, had argued that, with the existence of nuclear weapons, the aims of war had become disproportionate to the risks involved, the threat of reprisal being one of the foundation stones of a strategy of deterrence.

↑ **General André Beaufre**

General Charles Ailleret

Like General Gallois, General Beaufre developed his theory in the early 1960s. He argued that uncertainty was the key factor in deterrence, with the inherent threat of escalation. He also believed that a deterrence capability must have massive power of destruction, great precision and be able to penetrate through enemy defences.

Another major figure in strategic thought on nuclear defence, **Charles Ailleret** was also an Army officer who made a name for himself early on due to his interest in atomic weapons. He was a Colonel when, in 1950, he held a lecture on the possibilities of atomic warfare at the *École Supérieure de Guerre*.

Two years later, he took over as head of Special Weapons Command, tasked with exploring how to protect France from the new bomb, as well as how to obtain it. As head of Joint Forces Special Weapons Command, le *Commandement interarmées des armes spéciales* (since 1958), he was in charge of ordering the detonation of Gerboise Bleue on 13 February 1960. General Ailleret was thus both a practitioner and a theorist of nuclear deterrence.

In 1967, by then Chief of Defence Staff, he wrote a visionary paper setting out the "all-azimuths strategy", so relevant to France's current concept of nuclear deterrence, in light of the range of the missiles now held by France.

"(...) It appears that, in order to deal with these kinds of situation, our country must be able, as far as is possible, to dissuade, thanks to the action we might take, those who might consider taking our territory or destroying it with bombs. Our country must therefore be as strong as possible, on its own, taking account of its own resources and the philosophy of life held by those who live here. In the arsenal of modern weapons, those which, by far, have the highest yield, in other words, which are the most effective for a given price, are nuclear weapons. It is also these weapons which, thanks to their long-range action, are capable of deterring attack, since the very prospect of their terrible effects far outweighs the expected benefits of attack. So, if France is to prevent the risks it may be threatened with, it must have significant quantities – which do not have to be huge given their individual power – of megaton- yield ballistic devices of global range, that could deter anyone who wanted, from anywhere in the world, from using us or destroying us to further their belligerent objectives (...) Our autonomous force, as intrinsically powerful as possible, must also – since it is impossible to predict, for the generations to come, where in the world such a threat will come from – not be pointed in only one direction, towards a predetermined enemy, but be able to be used everywhere, that is, as we say in military parlance, an all-azimuths capability (...)"

General Charles Ailleret "Défense dirigée ou défense tous azimuts", *Revue de défense nationale*, december 1967

General **Lucien Poirier** also contributed to defining French nuclear strategy as part of research carried out at the Defence Ministry's planning and assessment centre (CPE, the *Centre de Prospective et d'Évaluation*, set up in 1964). In the 1960s, he was to develop the concept of critical aggression threshold, with the idea that the attacker must be forced into engaging more powerfully, notably through recourse, as a dissuasive manoeuvre, to a test to force it to sign its crime. Such a test, directly linked to the challenge to a nation's "vital interests", could, he believed, involve the use of Tactical Nuclear Weapons (TNW). Contrary to what would later be seen as a shift in his thinking, at the time General Poirier rejected any possibility of a nuclear conflict using TNWs.

↑ **Lucien Poirier**

THE DAM: DEVELOPMENT AND GROWTH

After the success of the first test explosion in February 1960, the position of the Military Applications Division (DAM), which succeeded the New Technology Division (DTN) in September 1958, was assured in the French defence system.

Henceforth, while retaining its autonomy, the CEA/DAM had to manage its research activities, the transition to industrial production (including series production of nuclear warheads), and the development of full-scale tests, as well as operating within the framework defined by the Military Planning Act.

The CEA/DAM's activities were also subject to a monthly inspection by the Armed Forces-CEA Joint Committee, set up in June 1961, which held its first meeting the following October. This entailed technical and financial checks on how defence-related activities were carried out and for which the CEA was responsible as its share of the *Œuvre Commune* (Joint engagement); the Prime Minister's ruling setting out procedures for the military atomic programme (13 June 1961) had specified that the programme was a joint task between the Ministry of Defence and the CEA.

The programmes implied in this *Œuvre Commune* were the following: nuclear weapons, the nuclear steam supply systems used on nuclear-propelled vessels, strategic materials and non-proliferation. The tasks were divided very clearly: the Ministry of Defence was responsible for the design of all weapons systems, while the CEA/DAM was in charge of the design, manufacture and through-life support of nuclear warheads-including guaranteeing their reliability and safety-and then dismantling.

To implement this work programme, the DAM expanded its geographical base in 1957, setting up centres in Moronvilliers and Valduc (initially the BIII annex and, from 1962, a centre in its own right). In 1959, the Ministry of Defence's Limeil Centre was attached to the CEA. Valduc was then tasked with manufacturing nuclear assemblies used in nuclear weapons.

In 1962, the Ripault Centre opened. Its primary task was to develop implosion systems. In 1965, to deal with the complexity of the problems arising from the militarization of devices, the DAM decided to set up the CESTA, the Aquitaine Scientific and Technical Research Centre, specifically tasked with the mission carried out until then by the Vaujours Centre.

The first generation of weapons produced by CEA/DAM were fission devices. During a meeting of the Council of Ministers on 18 July 1962, the Minister for Scientific Research, Atomic Energy and Space Questions, **Gaston Palewski**, announced the development of France's first operational nuclear device, the AN 11. Two years later, it was in service on the *Mirage IV* aircraft.

The challenge had been met with great speed by the DAM and the Armed Forces. Within a very short space of time, the DAM had developed a less basic, more sophisticated weapon, the AN 21.

↑ Mirage IV-A

Name of the nuclear warhead	Date in service	Vector
AN 11	1964-1966	Mirage IV-A
AN 21	1965-1967	Mirage IV-A
AN 22	1967-1987	Mirage IV-A

↑ AN-11

↑ 1998

LE RIPAULT

↓ 2001

CESTA

↗ 1966

ACCESS TO THE H BOMB AND THE KEY ROLE OF NUCLEAR TESTING

The issue of developing a thermonuclear weapons capability was raised very early on at the CEA/DAM, especially in light of the fact that three other Nuclear Powers had quickly developed them: the United States in 1952, Russia in 1953 and Great Britain in 1957. When preliminary discussions on building France's Strategic Oceanic Force (FOST) started in 1961; the DAM proposed equipping it with thermonuclear weapons. The Armed Forces, however, preferred an enhanced fission device, which seemed more easily accessible at the time (and that would give rise to the M 41 warhead), thus putting off development of the H bomb.

Nonetheless, in light of the speed of China's progress on its military nuclear programme (China tested its first A bomb in 1964), **General de Gaulle** put pressure on the CEA/DAM to ensure that France would not be left behind. In fact, a small detail had not escaped his notice: China's first test used enriched uranium (not plutonium as France had done), which led to the supposition that it was making rapid progress in the area of thermonuclear technology (in France, the first ingot of highly enriched uranium was not produced until 1967, at the Pierrelatte plant).

Paradoxically, it was only belatedly, not until January 1966, that the French President officially announced that it was a priority, during a visit to Limeil. China's H bomb test in June 1967 then put even greater pressure on the DAM, which finally found a solution to overcome the last obstacle in its way to developing thermonuclear technology. This solution, obtained through physics and laboratory research, was confirmed by the detonation of the Canopus device in August 1968.

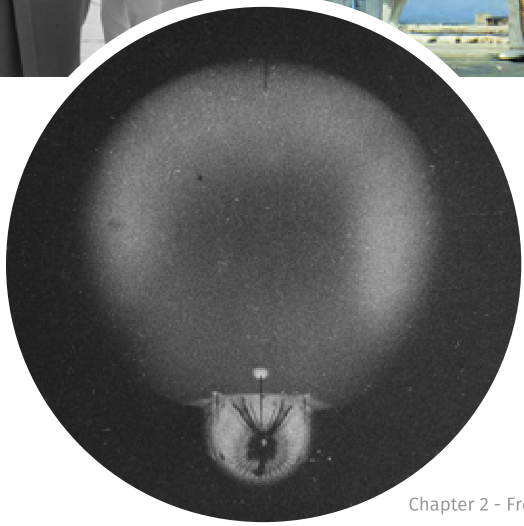
From 1960 on, the DAM carried out nuclear tests to certify the operational reliability and safety of nuclear weapons (to ensure the weapons would not be accidentally triggered). At the time, this was the only way to underpin the credibility of France's nuclear deterrence capability. For this purpose, the Division in charge of Nuclear Test Centres (DIRCEN) was created in 1964, replacing the Joint Forces Special Weapons Command (CIAS).

With the independence of Algeria, France was forced to seek an alternative location for its full-scale nuclear tests. One of the clauses in the 1962 Evian agreements between France and Algeria specified that tests could continue up until 1966. By then, France would be in a position to pursue its test campaigns in French Polynesia, four years after setting up the CEP (Pacific Testing Centre).

However, in addition to the technical difficulties entailed in conducting atmospheric and underground nuclear tests, there were diplomatic problems. A number of Nuclear Powers (Russia, United States and Great Britain) were pursuing various initiatives, including a moratorium on tests from 1958 to 1961, and the signature of the 1963 Moscow Treaty banning nuclear tests other than underground tests. This interfered with France’s test campaigns, an issue that was all the more sensitive as many nations openly opposed France's nuclear test policy.

This policy was key to the DAM being able to pursue its actions: apart from the guarantees it provided in relation to deterrence, it set the pace of work at the DAM, defining ambitious performance objectives to be met each year. Exceptionally, no French nuclear tests were conducted in 1969. They were cancelled for financial reasons.

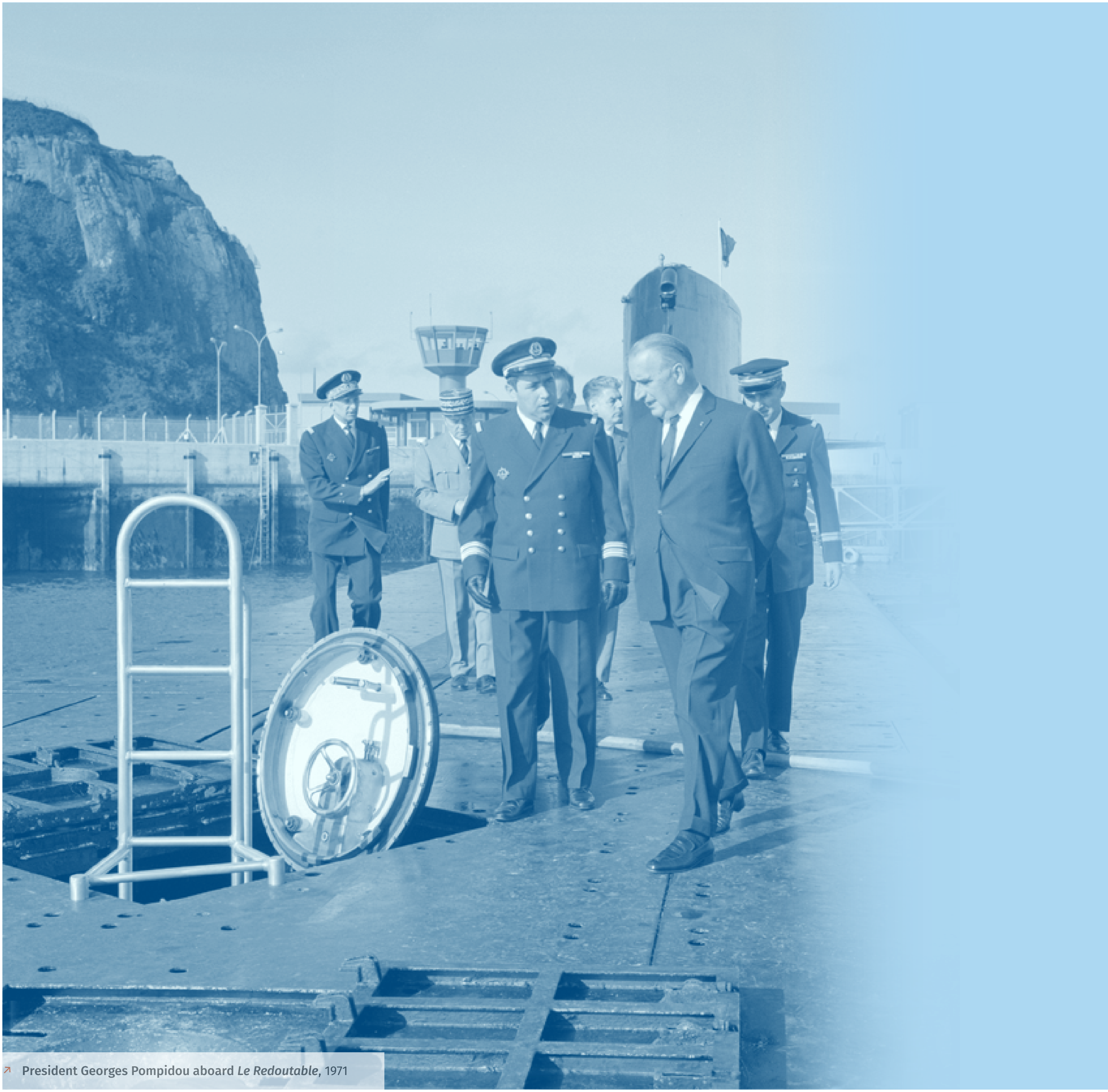
General de Gaulle in Mururoa ↗
for the Bételgeuse balloon burst test, September 1966



← **First seconds of the Bételgeuse burst**

↗ **Aldebaran, the first barge test,** Mururoa, July 1966

↗ **Canopus, the first thermonuclear bomb test (balloon burst),** Fangataufa, August 1968



President Georges Pompidou aboard *Le Redoutable*, 1971

3

CONSOLIDATING FRANCE'S DEFENCE NUCLEAR CAPABILITY 1969–1981

When **General de Gaulle** left government in 1969, France had acquired the first component of its nuclear force (FAS bombers) and had succeeded in developing thermonuclear technology. He left his successors with the task of consolidating and developing the now operational deterrent device.

Under President **Georges Pompidou**, strategic ground-based missiles (second component of the FAS) and SLBM-deployed strategic missiles (FOST) were thus both brought into service in 1971.

To achieve this, the CEA/DAM developed several new types of nuclear warhead: the MR 31 for S 2 ground-based missiles deployed at the Plateau d'Albion, the MR 41 for M 1 and M 2 missiles deployed on SSBN, and the TN 60 and TN 61 designed for the next-generation SSBN-deployed M 20 missiles.

Also in the early 1970s, the CEA/DAM, as requested by the government, developed tactical nuclear weapons. This led to the deployment of a common tactical warhead, the airborne AN 52 warhead from 1972 and, two years later, the AN 51 warhead on *Pluton* ground-based missiles.

Ramping up nuclear capabilities in this way would not have been possible at the time without full-scale nuclear tests, to obtain experimental validation for the programmes developed by the DAM. With regard to testing, a policy was therefore implemented to approve nuclear warheads before the designs could be put into series production.

1969

First test at sea, from the SSBN *Le Redoutable*

1970

Jean Viard took over from Jacques Robert as Director of the DAM

Parliament adopted **the 1971-1975 LPM**

1971

Several members of the Armed Forces-CEA Joint Committee were killed in a plane crash on their way to Pierrelatte

The **first unit of nine S 2 strategic ground-based missiles** became operational at the Plateau d'Albion

Le *Redoutable*, the first SSBN, became operational

1972

The **second unit** of nine **S 2 strategic ground-based** missiles became operational at the Plateau d'Albion

The Government published its **White Paper on National Defence**

Jacques Chevallier took over from Robert Camelin, who had replaced Jean Viard, as Director of the DAM

The **first AN 52 tactical nuclear weapons** were brought into service on *Mirage III* aircraft

1973

Tactical nuclear weapon tested in operational configuration, launched from a *Mirage III*, off the coast of Mururoa

1974

***Pluton* missiles carrying AN 51 warheads brought into service**

French atmospheric tests ended

1975

First nuclear test in an underground shaft, beneath Fangataufa atoll

1976

Parliament adopted the **1977-1982 LPM**

1978

The **first Naval-Air Force tactical nuclear weapons** were delivered to the *Clemenceau* aircraft carrier and, two years later, to the Foch aircraft carrier.

DEVELOPMENT OF FRANCE'S STRATEGIC TRIAD

Following deployment of the first component of the FAS, in 1964, the priority was to develop a Strategic Nuclear Forces (FNS) triad, made up, in addition to the airborne component, of a submarine and a ground-based component. This diversified the means of deterrence available to the President.

Although the French Government had decided in July 1955 to build a uranium fuel/heavy water-moderated nuclear-powered submarine (the Q 244 programme), its construction had been held up from the outset by design problems. Three years later, this had been rectified and, in 1960, the decision was taken to build a prototype on land, using enriched uranium, at the CEA's Cadarache site. The reactor reached criticality in 1964. Meanwhile, the French Government had decided to build the first nuclear-powered ballistic missile submarine (SSBN), named *Le Redoutable*. Any advance in this field was closely related to the state of progress on ballistic missile technology.

France demonstrated its ability in 1965 when it sent its first artificial satellite into orbit using a *Diamant rocket*. For this, the French Defence Ministry set up the Landes Test Centre (CEL) in 1962, thereby demonstrating French expertise through testing.

Officially launched by **General de Gaulle** in Cherbourg in March 1967, *Le Redoutable* was commissioned in December 1971, carrying the M 1 missile with the MR 41 warhead. From that moment on, France's Strategic Oceanic Force (FOST) became fully operational.

At the same time, the strategic ground-based ballistic missiles component was developed, with the Plateau d'Albion chosen to house this new FAS component. Thus, the first unit of nine S 2 strategic ground-based missiles, armed with MR 31 warheads, came into service at the Plateau d'Albion in August 1971, followed by a second unit, also of nine missiles, the following April.

Name of the nuclear warhead	Type of weapon	Date commissioned	Vector
MR 31	Fission	1971-1980	S 2 missile on the Plateau d'Albion
MR 41.1	Fission	1971-1973	M 1 and M 2 on SSBN
MR 41.2	Fission	1973-1979	M 1 and M 2 on SSBN
TN 60	Thermonuclear	1976-1980	M 20 missile on SSBN
TN 61	Thermonuclear	1980-1996	M 20 (on LBM) and S 3 missiles (on the Plateau d'Albion)

President **Georges Pompidou** was thus the first French President to have the strategic triad available.

Deploying the triad as part of France's nuclear deterrence strategy also coincided with the publication, in June 1972, of the first White Paper on National Defence, commissioned by the Minister of Defence, **Michel Debré**. For the first time, the French Government stated publicly that the sole purpose of nuclear deterrence was to protect the "vital interests" of the nation, defined solely with reference to what constitutes France itself.

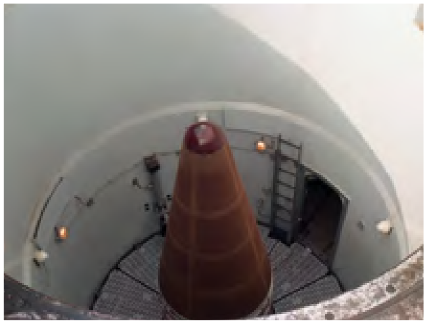
The development of the Strategic Nuclear Forces went hand-in-hand with a series of major technological developments:

- **A REDUCTION IN THE MASS OF NUCLEAR WARHEADS** to make them smaller, which justifies the replacement of TN 60 by TN 61.
- **MULTIPLE NUCLEAR WARHEADS**, i.e. "MIRVING", which were brought into operation in 1985, with the TN 70 on the SSBN-launched M 4 missile, designed to saturate enemy defence systems.

Meeting between President Georges Pompidou and the Director of the DAM, Jacques Chevallier, 7 December 1972

"I shared all my thoughts with him, in particular regarding the problem of multiple warheads. The President listened in silence until I had finished talking, then asked me:
— Do you think that France is able to resolve this problem?
I replied:
— Mr President, France took a much greater risk when she decided to embark on building missile-launching submarines.
He then said to me:
— I have every confidence in you.
And that was the end of our meeting."

Account given by Jacques Chevallier on the occasion of the DAM's 40th anniversary



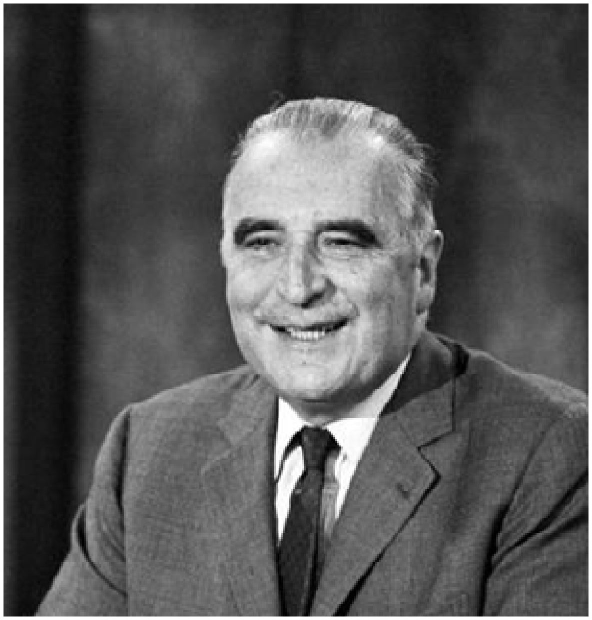
↑ *Mirage III* equipped with the AN 52

↑ Missile on the Plateau d'Albion

↑ Envelope commemorating the launch of *Le Redoutable*, the nuclear-powered ballistic missile submarine

From left to right: François-Xavier Ortoli, Minister for Industrial and Scientific Development Robert Hirsch, Chairman of the CEA Michel Debré, Minister of Defence Francis Perrin, High Commissioner
Bruyères-le-Châtel, 1970

Jacques Chevallier



Georges Pompidou

DEVELOPMENT OF TACTICAL NUCLEAR WEAPONS

French government had planned the development of tactical nuclear weapons (TNWs) in 1963 and, three years later, in 1966, it was decided to launch production, at the very moment when France withdrew from NATO integrated military command and the USA stopped making its tactical nuclear arsenal available to France.

At the time, the Defence Ministry's planning and assessment centre (CPE) advocated that possessing TNWs, especially a ground-based vector, would help link any military action by French field forces to the threat of using nuclear weapons. Furthermore, the Armed Forces considered the use of TNWs as a capability to "test" the intentions of the enemy. The 1972 White Paper on National Defence concluded from this that "*conventional military manoeuvring was an integral part of the political handling of deterrence*".

It was, however, under President **Valéry Giscard d'Estaing's** government that the role attributed to TNWs reached its climax since, at the time, he considered it not only an instrument of deterrence but also an instrument of combat.

The CEA/DAM had developed a tactical nuclear weapon used by both the Land Forces and the Air Force since 1964, in response to financial concerns (to cut the cost of weapons development) as well as organizational issues (to lighten the DAM's workload). The common tactical warhead was thus used by the Tactical Air Force (FATAC), from 1972, equipped with the AN 52, and later, from 1974, the Land Forces, equipped with the AN 51.

The AN 51 was the device tested in the Aldebaran nuclear test in July 1966, the first atmospheric test launched from a barge at the CEP, the Pacific Testing Centre. The AN 52 was tested in an operational configuration launched from a *Mirage III* aircraft, off Mururoa-the Tamara test in August 1973.

As of 1978, it was decided to modernize the tactical nuclear forces, first with the project to develop the ASMP medium-range air-to-ground missile, and second with the *Hadès* programme to develop a ground-based missile with a longer range than the *Pluton*, greater precision and enhanced penetration capability.

This programme was also developed in response to a political priority: in extending the range of the missile, the aim was to appease the concerns of the Federal Republic of Germany that France viewed it as a buffer for its own protection.

Around the same time, under government's orders, the DAM launched (in 1976) studies on producing an Enhanced Radiation Weapon, also known as a neutron bomb, possibly to be used with the *Hadès* missiles.

Name of the nuclear warhead	Type of weapon	Date commissioned	Vector
AN 52	Fission	1972-1991	*Mirage III-E, Jaguar* and *Super-étendard*
AN 51	Fission	1974-1993	Tank-launched *Pluton* missile

↑ **Tamara test, 28 August 1973**

Pluton missile

Jaguar aircraft

↑ **Loading an ASMP missile onto a *Super-Étendard***

NUCLEAR TESTING STRATEGY

The evolution of French nuclear weapons made it essential to pursue a test policy, as fission weapons were being replaced by enhanced fission weapons, and then by thermonuclear weapons.

The division of tasks between the CEA/DAM and the Armed Forces had been defined in the mid-1950s. It resulted in 1964, in setting up the DIRCEN, the Division in charge of Nuclear Test Centres, headed by a general officer, who was assisted by the DAM's Test Director. The Armed Forces were tasked with providing logistics support for operations, while the DAM was to plan physical tests on the device, perform measurements during the test and use the data to develop nuclear warheads.

To militarize weapons, experimentations were needed in particular to test their capabilities against enemy anti-missile systems, as well as to reduce their size to deploy multiple warheads on M 4 missiles. In April 1974, the decision was taken to produce the M 4 missile based on MIRV technology, which gave it multiple independently targetable warheads. The CEA/DAM was put in charge of developing the re-entry vehicle. Around ten years later, advances would focus on radar discretion.

To take an example illustrating what this meant, the 1973 nuclear test campaign validated a new initiator system, leading to a lighter megaton warhead and preparations for bringing the M 4 missile into service a decade later.

Preparing ahead for the time when it would no longer use the test center in Algerian Sahara, as stipulated in the Evian agreements (1962), France created the Pacific Testing Centre (CEP), after selecting two atolls in Polynesia, Mururoa and Fangataufa. These sites had the advantage of being very remote from any densely populated area, unlike the US site in the Nevada Desert, for example.

France carried out atmospheric tests at the CEP from 1966 to 1974, before switching to tests in shafts, as of 1975. These tests proved to be particularly productive, in terms of the measurements taken as well as in terms of consistent testing conditions, since tests could be performed regardless of weather conditions.

Type of nuclear test	**Number**
Atmospheric, in Reganne, 1960 to 1961	4
In underground tunnels in In Ecker, 1961 to 1966	13
Atmospheric (launched from barges, aircraft or from beneath a balloon), in French Polynesia, 1966 to 1974	46
In shafts: under the reef crown or under the lagoon, in French Polynesia, 1975 to 1991	141
The last campaign: In shafts, under the lagoon, in French Polynesia, 1995 to 1996	6
TOTAL	**210**

Rigel test, from a barge, Fangataufa
24 September 1966

Rhea test, balloon test, Mururoa
14 August 1971

Ilus test, under the reef crown, Mururoa
21 June 1980

Pitthée test, under the lagoon, Mururoa
14 June 1991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CXX MARDI 30 JANVIER 1996 (N° 16 003)
Après le sixième tir dan
Chirac : arr
des essais n
La dernière campagne
La France aime être aimée du monde entier. Pendant six mois, être aimée n'a pas été si facile. Notre image de nation généreuse et pacifique, tournée vers les autres, porteuse d'un message universel, a été ternie – pourquoi se le cacher ? – par la reprise des essais nucléaires. La fiabilité de notre dissuasion avait un prix. Nous l'avons cher payé.
PAR ALAIN PEYREFITTE
M. Jacques Chirac a eu le courage de faire ce qu'il fallait pour rendre leur « crédibilité »
La France va prendre
dans le monde » et aussi «
Jacques Chirac a annoncé hier soir « l'arrêt définitif » des essais nucléaires français dans le Pacifique-Sud. Le sixième et dernier essai de la campagne actuelle a eu lieu samedi.
● « Grâce à l'ultime série qui vient d'être effectuée, la France disposera durablement d'une défense fiable et moderne. La sécurité de notre pays, celle de nos enfants est assurée », a déclaré le président de la République lors d'une allocution télévisée.
● Il a ajouté que « la France va jouer un rôle actif et déterminé pour le désarmement dans le monde et aussi pour une meilleure défense européenne ». M. Chirac prendra des « initia-

4

SHIFTS AND CONTINUITY 1981–1996

Shifts in political power, with, for the first time under the Fifth Republic, an opposition party candidate becoming President, did not bring about a challenge to France's nuclear defence policy. On the contrary, political continuity regarding the issue was quite remarkable.

Changes in the geostrategic situation, with the end of the Cold War, led the new President to call for a review of the basic principles underlying France's nuclear deterrence. Although deterrence remained the priority in defence policy, consolidating its strategic aspects, a radical shift came about with a focus on disarmament and non-proliferation.

This was the backdrop to **President François Mitterrand**'s decision to impose a moratorium on nuclear tests as of 1992, which remained in place until the end of his second seven-year term in office. He also called for full-scale nuclear tests to be replaced by simulation.

On this issue, the CEA/DAM was already one step ahead, having explored the options in case of a possible limitation on nuclear tests (although not a complete ban) since 1989. Two years later, the Director of the DAM, **Roger Baléras**, backed by the Defence Minister, **Pierre Joxe**, launched the PALEN programme (*Préparation A une Limitation des Essais Nucléaires*).

This gave the CEA/DAM the opportunity to raise the profile of the pioneering research it had been conducting since the 1960s on high-power lasers and high-performance computing, two key factors in successfully developing and leading simulation technology.

The defence nuclear community argued that a final test campaign was essential before adhering to a total ban on nuclear tests. This was decided by President **Jacques Chirac** in 1995.

1983

Parliament adopted the **1984-1988 Military Planning Act**

President Mitterrand's speech to the UN on disarmament

1985

Decision made to design and produce the **TN 75** warhead

Alain Vidard took over from Jacques Chevallier as Director of the DAM

1987

Parliament adopted the **1987-1991 LPM**, which only applied to equipment

1988

Roger Baléras took over from Alain Vidard as Director of the DAM

1990

Parliament adopted the **1990-1993 LPM**

1991

Launch of the **PALEN programme** (*Préparation A une Limitation des Essais Nucléaires*) based on studies dating back to 1989

1992

Prime Minister **Pierre Bérégovoy** announced a **moratorium on tests** up to the end of the year

President Mitterrand signed the order suspending tests

Launch of the **AIRIX programme**: Radiographic and hydrodynamic facility built as part of the PALEN programme

French moratorium extended

1993

Preliminary design for the **MegaJoule Laser (LMJ)**

Lanxade Group set up to discuss the impact of suspending tests on the future of nuclear weapons

President Mitterrand stated that there would be no more tests before the end of his mandate

1994

In a speech given by **President Mitterrand** on nuclear deterrence, he announced his decision to develop a major **simulation programme**

Parliament adopted the **1995-2000 LPM**

Jacques Bouchard took over from Roger Baléras as Director of the DAM

1995

Decision taken to build the **LMJ facility at the CESTA** near Bordeaux

1996

After a final test campaign from September 1995 to January 1996, **President Jacques Chirac** announced **the definitive end of French nuclear tests**.

MODERNIZING THE NUCLEAR FORCES AND THE END OF THE COLD WAR

When **François Mitterrand** came to power in May 1981, he took on immediately the nuclear defence responsibilities held by all Presidents of the Fifth Republic. During the so-called "Euromissile Crisis" (1979-1987), a major Cold War crisis, Mitterrand spared no effort, in France and abroad, in arguing in favour of nuclear deterrence.

This led him, notably in a famous speech to the Bundestag in January 1983, to back the West German Chancellor in favour of deploying missiles in Western Europe, in a bid to offset the imbalance caused by the Soviet Union's deployment of SS 20 missiles.

Throughout this period, France's Strategic Nuclear Forces (FNS) were being extensively modernized, with the deployment of multiple warheads on missiles carried on SLBMs and significant advances in radar discretion and hardened warheads. Such advances were also facilitated by significant reductions in warhead mass and volume, which made it possible to design longer-range weapons.

Name of the nuclear warhead	Type of weapon	Dates in service	Vector
TN 70	Thermonuclear	1985-1996	M 4 missile on SSBN
TN 71	Thermonuclear	1987-2004	M 4 missile on SSBN

From 1985 on, each M 4 missile could carry six nuclear warheads, implying a significant increase in the arsenal carried aboard SSBNs (sixteen missiles each equipped with six nuclear warheads) and thus the FNS arsenal. In addition, the technology for the TN 71 warhead had been defined in 1983. It was lighter than the TN 70 and allowed significantly enhanced radar discretion.

The table on the right shows the size of the FNS arsenal over the years, as made public by different French Presidents.

These figures give an idea of CEA/DAM's workload over the years and of its changing industrial capacity, particularly at the Valduc and Ripault Centres.

Year	Number of nuclear warheads
1983	98
1986	150
1987	300
1994	500
2008	300
2015	300

Weapons which were formerly called tactical nuclear weapons had undergone significant upgrades and, by 1984, were known as pre-strategic weapons, for example, the medium-range air-to-ground cruise missile (ASMP), which an aircraft pilot could fire at a safe distance thanks to ramjet technology.

Name of nuclear warhead	Type of weapon	Dates in service	Vector
TN 80	Thermonuclear	1986-1988	Airborne ASMP missile *Mirage VI-P*
TN 81	Thermonuclear	1988-2009	Airborne ASMP missile carried on *Mirage IV-P, Mirage 2000-N* and *Super-étendard*
TN 75	Thermonuclear	Since 1997	M 45 missile on new-generation SSBN (SNLE-NG)
TNA	Thermonuclear	Since 2009	ASMP-A missile on Mirage 2000-N and Rafale

When the Cold War ended in 1991, France had only strategic weapons left. This was the outcome of Mitterrand's doctrinal review and signalled the dawn of the new focus on disarmament.
It can be said that the strengthening of France's nuclear posture and, therefore, the build-up of its arsenal throughout the 1980s, certainly played a significant part in blocking the destabilizing manoeuvre of the Soviet Union, and, consequently, in defusing the Euromissile crisis.

JUILLET 1992 NUMERO 4

LE TRAIT D'UNION

LES ESSAIS, UN MAILLON DE LA DISSUASION

Paris, 8 Avril (AFP) - Le Premier Ministre Pierre Bérégovoy a annoncé mercredi à l'Assemblée nationale la "suspension cette année des essais nucléaires de la France dans le Pacifique" sur instruction du Président de la République.

"EXTRAIT DE LA LETTRE DU DAM AU PERSONNEL"

La situation de maintien de la dissuasion nucléaire réaffirmée par le 1er Ministre tout en décidant une suspension des tirs de la Campagne 1992 nous pose un véritable problème... J'ai été longuement reçu par le Ministre de la Défense qui s'est déclaré prêt à nous apporter toute l'assistance nécessaire pour régler au mieux la situation.

La préparation de la Loi de Programmation Militaire se poursuivra donc dans un esprit de continuité.

R. BALERAS

Extract from "Le trait d'union"
The CEA/DAM Test Division's newsletter

↑ **Building the AIRIX facility at the experiment centre in Moronvilliers, November 1995**

← **Nuclear testing resumed with the Thétys test**
5 September 1995
Lifting the container, a genuine physics laboratory containing the device and measurement instruments, into position

FRANCE'S DISARMAMENT POLICY

According to President **François Mitterrand**, disarmament was only possible if the potential adversary also undertakes to disarm. The end of the Cold War brought about a radical shift in this regard. It allowed Mitterrand to follow the principle that France, thanks to its status as a Nuclear Power, could effectively influence disarmament negotiations. Hence the policy implemented consisted in creating a *fait accompli*, in order to have "something to bring to the table" (i.e. the build-up of France's nuclear arsenal).

To put this in perspective, the latter should be seen in comparison to the size of the Soviet Union's nuclear arsenal just before the end of the Cold War, namely, 25,800 nuclear warheads, including 12,500 strategic weapons. Significant cuts in the number of nuclear warheads held by France were made from the mid- 1990s, with the implementation of unilateral disarmament measures adopted by France. It was at that time that the idea of "sufficient force" began to develop. This is now one of the cornerstones of French nuclear doctrine.

Year	French disarmament measures announced and implemented
1991	• Early withdrawal of AN 52 warheads from service on board bombers • Hadès Programme cut to 30 missiles (120 were planned) • S 45 missile project, which was to have replaced the S 3, scrapped
1992	• Moratorium on nuclear tests • Hadès Programme stopped • Nuclear forces alert level lowered: 2 or 3 SSBNs on duty at sea, nuclear force aircraft response times doubled, number of nuclear exercises halved (between 1990 and 1993) • Number of SSBNs (SNLE-NG) planned for construction cut from 5 to 4 • Production of weapons-grade plutonium stopped
1993	• End of *Pluton* weapons system mission • UP1 plant at Marcoule closed down
1996	• President **Jacques Chirac** announced the definitive end to French nuclear tests, the definitive closure of the CEP, and the dismantling of all weapons-grade fissile materials production facilities • Highly enriched uranium production stopped at the Pierrelatte site • Ground-based missiles on the Plateau d'Albion no longer operational • France signed the CTBT • Final withdrawal of the Hadès weapon system.
1998	• France ratified the CTBT
2008	• President **Nicolas Sarkozy** announced the number of FAS squadrons would be cut from 3 to 2
2015	• Transparency measures announced by President **François Hollande**: details of France's arsenal specified (3 x 16 missiles carried on SSBNs (SNLE-NG)and 54 ASMP-A vectors) and visits organized for the media to sites no longer holding nuclear weapons (Plateau d'Albion and the Luxeuil base)

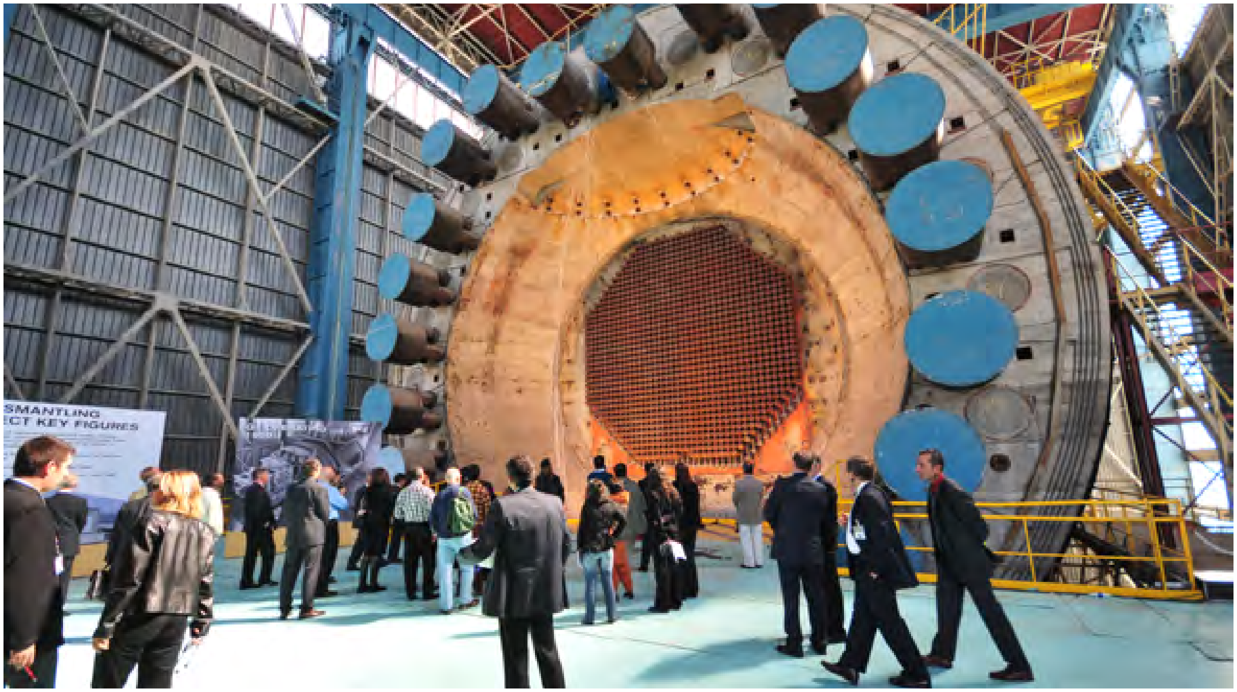
At that time, French disarmament policy linked disarmament and non-proliferation issues. This is the yardstick by which to measure France's commitment when it ratified the Non-Proliferation Treaty (NPT) in 1992.

For President Mitterrand, disarmament and deterrence are inseparably linked, the aim of one being to reduce the risk of war, while the aim of the other is to prohibit it. In 1996, France signed the Comprehensive Nuclear Test Ban Treaty (CTBT) and ratified it two years later.

Visit by the International Experts
16 September 2008

Dismantling at Pierrelatte

← ↓ **Dismantling at Marcoule**




PLUTONIUM
PROCESSING UNIT
1980
cea

FROM THE MORATORIUM TO THE DEFINITIVE END TO NUCLEAR TESTS

The moratorium on tests, issued in April 1992, was imposed by the government on the CEA/DAM and the Armed Forces, without any real discussion. At the time, this gave rise to incomprehension within the defence nuclear community.

The decision reflected **François Mitterrand**'s desire to make a move towards disarmament (following the announcement of the Soviet moratorium in October 1991), even though he came up against technical arguments in favor of pursuing full-scale tests, as advocated by the Director of the DAM.

Roger Baléras believed that, before entirely switching over to simulating weapon performance, tests, involving highly instrumented physical experiments, were essential in order to validate the principle of "robust warhead design", a nuclear device with low sensitivity to technological changes. In addition, much had been learned within the DAM thanks to the problems encountered by the United States following the 1958-1961 moratorium (when they had sought to resume tests and approve their new nuclear warheads).

In July 1993, to appease tensions and deal with the period of Cohabitation in government, the President appointed a commission chaired by Chief of Defence Staff, Admiral **Jacques Lanxade**. The commission's report concluded that resuming tests in French Polynesia was necessary.

Nonetheless, this recommendation was not followed up until two years later, when President **Jacques Chirac** decided to go ahead with a final series of nuclear tests from September 1995 to January 1996. Six devices were detonated, five of which were designed to validate the transition to the Simulation Programme, and one to approve the TN 75 warhead (for M 45 missiles equipping SSBNs). The TN 75, on which design work began in 1985, was an extremely optimized device compared to its predecessors, particularly thanks to improved radar discretion technology and hardening to facilitate penetrating enemy anti-missile systems.

President **Jacques Chirac**'s political undertaking led to the definitive end of nuclear tests and the dismantling of the Pacific Testing Centre (CEP). France was the first nation in the world to dismantle its nuclear testing centre, and to take such a measure unilaterally. This decision was a logical prelude to France's signing of the Comprehensive Nuclear Test Ban Treaty (CTBT), in September 1996, and its commitment to conclude a treaty banning the production of fissile materials for nuclear weapons (the "Cut-off Treaty"). In so doing, the French government wanted to set an example and take concrete action towards disarmament, in application of Article Six of the NPT.

Président	Number of nuclear tests
De Gaulle	31
Pompidou	23
Giscard d'Estaing	62
Mitterrand	88
Chirac	6
TOTAL	**210**

Xouthos, the last nuclear test
Fangataufa, 27 January 1996

Mirage room, video wall

5

SIMULATION, THE ULTIMATE TOOL GUARANTEEING THE FRENCH NUCLEAR WEAPONS SINCE 1996

Since the end of the Cold War and, more specifically, since 1996, the Simulation Programme became the only way to guarantee the performance and safety of French nuclear weapons. As a result, it underpins the ultimate political and technical credibility of France's nuclear deterrence

At the CEA/DAM, this credibility is ensured by handing down knowledge, primarily between weapon designers. This fundamental approach is becoming increasingly important as we move away from the era of large-scale nuclear tests.

Now, almost twenty five years have passed since the end of nuclear tests. This is irreversible, hence the importance of the CEC (*Capitalisation et Exploitation des Connaissances*) project launched in April 1996 to capitalize on and use knowledge. On a wider scale, this credibility is also ensured by sharing and comparing knowledge and practices between scientists and engineers at the DAM and those in the scientific community as a whole.

This is also the reason behind opening up the large-scale facilities of the Simulation Programme, which consists in scientifically and economically supporting the National and European industrial landscape, notably by pooling the big facilities of the programme.

Since the beginning of the new millennium, the Simulation Programme has become a key strategic tool in boosting the growth of many French companies, mainly by reducing their R&D costs by enabling them to model their future products, thus making them more competitive in the international markets.

Also, thanks to the Simulation Programme, the CEA/DAM has reinforced its ability to manage new large-scale projects in a spirit comparable to that which reigned over the preparations for and performance of nuclear tests: the ability to rise to real scientific, technological and industrial challenges.

Furthermore, the French Ministry of Defence has estimated that the Simulation Programme has reduced the budget required for guaranteeing nuclear weapons by 60% compared with that required at the time of nuclear testing.

Last, the Simulation Programme has raised the CEA/DAM to a new position within the French defence system.

1996

Decision taken to launch the **Simulation Programme**

Beginning of **DAM Restructuration**

End of operational alert for ground-based strategic missiles at the Plateau d'Albion

Parliament adopted the **1997-2002 LPM**

1997

Building of the **Laser Integration Line (LIL)**

First SSBN New Generation was brought into service, carrying m 45 missiles equipped with TN 75 warheads

The last *Hadès* missile was dismantled

The uP1 reprocessing plant at Marcoule was decommissioned

1998

President Chirac inaugurated the LIL facility at the CESTA

Dismantling the CEP facilities was **completed** and the **DIRCEN** disbanded

1999

Experimental **laser facilities at the Limeil Centre** were transferred to the CESTA

First test to qualify the **AIRIX facilty** was carried out at the Moronvilliers Centre

Restructuring the DAM was completed including **closing down the Limeil Centre**

2000

Alain Delpuech took over from Jacques Bouchard as Director of the DAM

Inauguration of the **AIRIX facility**

As part of reorganization at the CEA, **the nuclear propulsion unit was attached to the DAM**

2001

The **AIRIX facility** was commissioned

TERA, a supercomputing power of five teraflops came into service at the DIF Centre

2002

A **policy of openness** implemented as part of the Simulation Programme

The **LIL facility** was commissioned

2003

Parliament adopted the **2003-2008 LPM**

Beginning of the **building of the LMJ** (MegaJoule Laser) at the CESTA

The nominal energy characteristics of the LMJ were obtained on a **LIL** beam

CEA's Research and Technology Computing Centre **(CCRT)** was set up at the DIF Centre

2004

To strengthen ties between civil research, defence research and industry, **a Framework Agreement between the CEA and the DGA** (*la Délégation Générale pour l'Armement*, French Defence procurement agency) was signed

The DAM delivered the **last batch of TN 75 Missiles** equipping M 45 missiles

2005

The LIL was opened to the scientific community, leading to the first plasma physics experiments

At the CEA/DAM Île-de-France Centre, a new computer with computing power of 60 teraflops was brought into service, **developed by Bull and named TERA 10**

2007

Decision taken to launch the production phase of the **Airborne nuclear warhead (TNA)**

Daniel Verwaerde took over from Alain Delpuech as Director of the DAM

2008

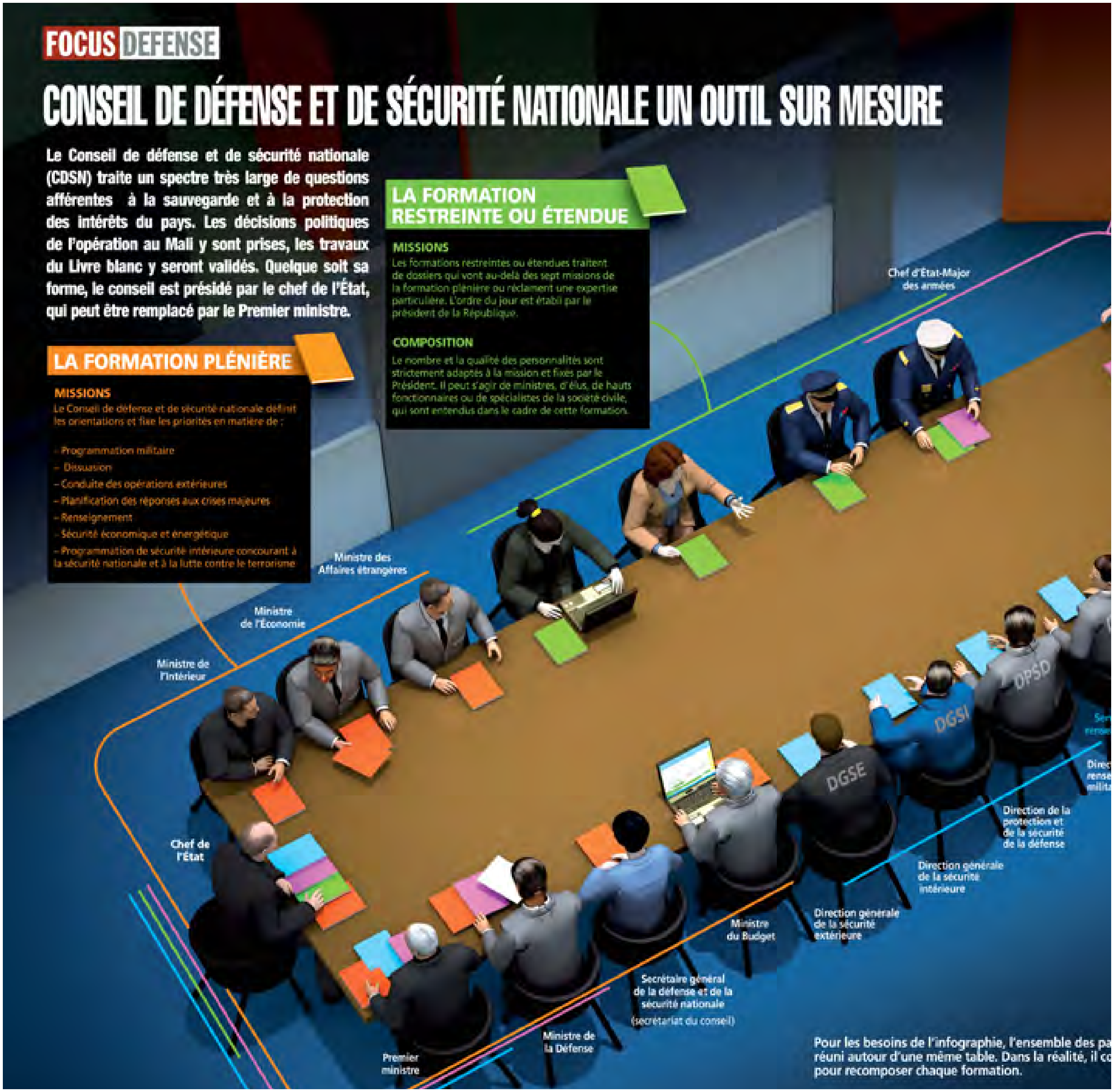
Priority given to the Simulation Programme was confirmed in France's **White Paper on Defence and national Security**

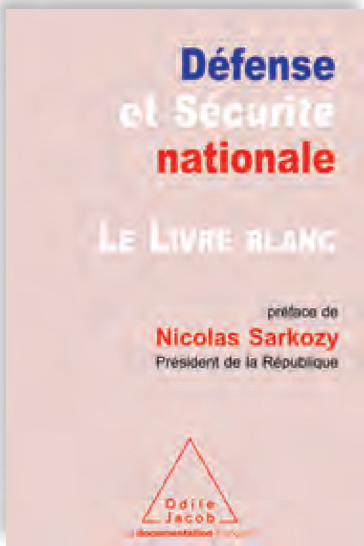
2009

Parliament adopted the **2009-2014 LPM**

ASMP-A missiles equipped with TNA warheads brought into service on the *Mirage 2000 N-K 3*

Director of the DAM officially made a member of the **Nuclear Weapons Council**


FOCUS DEFENSE
CONSEIL DE DÉFENSE ET DE SÉCURITÉ NATIONALE UN OUTIL SUR MESURE
Le Conseil de défense et de sécurité nationale (CDSN) traite un spectre très large de questions afférentes à la sauvegarde et à la protection des intérêts du pays. Les décisions politiques de l'opération au Mali y sont prises, les travaux du Livre blanc y seront validés. Quelque soit sa forme, le conseil est présidé par le chef de l'État, qui peut être remplacé par le Premier ministre.
LA FORMATION PLÉNIÈRE
MISSIONS
Le Conseil de défense et de sécurité nationale définit les orientations et fixe les priorités en matière de :
- Programmation militaire
- Dissuasion
- Conduite des opérations extérieures
- Planification des réponses aux crises majeures
- Renseignement
- Sécurité économique et énergétique
- Programmation de sécurité intérieure concourant à la sécurité nationale et à la lutte contre le terrorisme
LA FORMATION RESTREINTE OU ÉTENDUE
MISSIONS
Les formations restreintes ou étendues traitent de dossiers qui vont au-delà des sept missions de la formation plénière ou réclament une expertise particulière. L'ordre du jour est établi par le président de la République.
COMPOSITION
Le nombre et la qualité des personnalités sont strictement adaptés à la mission et fixés par le Président. Il peut s'agir de ministres, d'élus, de hauts fonctionnaires ou de spécialistes de la société civile, qui sont entendus dans le cadre de cette formation.
Chef d'État-Major des armées
Ministre des Affaires étrangères
Ministre de l'Économie
Ministre de l'Intérieur
Chef de l'État
Premier ministre
Ministre de la Défense
Secrétaire général de la défense et de la sécurité nationale
(secrétariat du conseil)
Ministre du Budget
Direction générale de la sécurité extérieure
Direction générale de la sécurité intérieure
Direction de la protection et de la sécurité de la défense
DGSE
DGSI
DPSD



Le maintien de la crédibilité technique

Le maintien de la crédibilité de notre dissuasion reposera largement sur les moyens scientifiques et techniques nécessaires à la préservation dans le temps de nos capacités nucléaires. Notre aptitude à assurer sur le long terme, de façon indépendante, la fabrication d'armes fiables et sûres doit être garantie.

En l'absence d'essais nucléaires et d'installation de production de matières fissiles à des fins explosives, le programme de *simulation* est donc un élément clé de la dissuasion. Il n'est pas destiné à la mise au point de nouvelles filières d'armes nucléaires, mais à préserver leur adaptation en fonction des phénomènes de vieillissement des armes, des évolutions des défenses et des mutations scientifiques et techniques.

À partir des résultats de l'ultime campagne d'essais, ce programme a pour objectif d'assurer la garantie de fonctionnement des têtes nucléaires en l'absence d'essais nucléaires. Il s'appuie principalement sur le laser mégajoule (LMJ), les moyens de radiographie des armes et les moyens de calcul intensif numériques. Il permet également le maintien dans la durée de la compétence des experts qui savent concevoir les armes.

↑ **Extract from the 2008 White Paper, page 171**

"(...) Nuclear deterrence will remain based on the permanent posture of its airborne and seaborne components, which are indivisible and complementary. Both contribute to all deterrence missions. Thanks to their performance, adaptability and characteristics, they will remain a credible instrument in the long term, while being structured in accordance with the principle of strict sufficiency. Upon discontinuing nuclear testing, France invested in simulation systems that ensure the safety and reliability of its nuclear weapons.

We must continue the necessary adaptation of our deterrence capabilities, in response to changes in the strategic environment, to shifting threats and changes in areas such as air defence, missile defence, and undersea detection. This implies renewing the two components and sustaining our nuclear warheads.

These two components, which boost our whole defence system and ensure the freedom of action of our forces, are supported by a range of conventional capabilities, thereby offering a broad range of strategic options. Several assets that contribute to deterrence may be deployed in conventional operations (...)."

↑ **Extract from the "Defence and National Security Strategic Review 2017", page 72**

"(...) As the Head of State, I am the guarantor of the long-term, for my responsibility as head of the armed forces is to protect our nation from threats, while looking several decades into the future.

Nuclear deterrence has played a fundamental role in maintaining peace and international security, particularly in Europe. I am firmly convinced that our deterrence strategy maintains all of its stabilizing virtues, a particularly valuable asset in the world which we see before us, one of competition between powers, disinhibited behaviours and the erosion of norms.

The fundamental purpose of France's nuclear strategy, the doctrinal bases of which I have just set out, is to prevent war.

Our nuclear forces are not directed towards any specific country and France has always refused that nuclear weapons be considered as a battlefield weapons. I hereby reaffirm that France will never engage into a nuclear battle or any forms of graduated response.

Furthermore, our nuclear forces have a deterrent effect in themselves, particularly in Europe. They strengthen the security of Europe through their very existence and they have, in this sense, a truly European dimension.

On that point, our independent decision-making is fully compatible with our unwavering solidarity with our European partners. Our commitment to their security and their defence is the natural expression of our ever-closer solidarity. Let's be clear: France's vital interests now have a European dimension.

In this spirit, I would like strategic dialogue to develop with our European partners, which are ready for it, on the role played by France's nuclear deterrence in our collective security.

European partners which are willing to walk that road can be associated with the exercises of French deterrence forces. This strategic dialogue and these exchanges will naturally contribute to developing a true strategic culture among Europeans (...)."

Speech of the President of the Republic on the Defence and Deterrence strategy, Ecole militaire, 7 February 2020

2010

An **agreement was signed by the CEA and the DGA to transfer the Gramat Research Centre (CEG) to CEA/DAM**

ASMP-A missiles equipped with TNA warheads brought into service on the *Rafale-F 3*

President Sarkozy visited the CESTA

The **Bull TERA 100**, with computing power of 1 petaflops, was brought into service at the DIF Centre

Inauguration of the **CEA's Very Large Computing Centre (TGCC)**

France and the United Kingdom signed two treaties at **Lancaster House**: a treaty on general defence and security cooperation and **a treaty on nuclear cooperation (Teutates Treaty)**

The DAM approved the **2010 computing standard** for guaranteeing nuclear warheads

2011

The DAM ends delivery of the TNA, before the last TN 81 warhead was withdrawn from operational service and dismantled

Decision made to build the PETAL **Petawatt Laser** at the LMJ facility

The DAM approved the **first Ouranos computer code standard** for conventional weapons systems

2012

The Strategic Air Forces (FAS) carried out the first evaluation firing of the ASMP-A system equipped with a TNA simulator

The National Tsunami Alert Centre (CENALT) was commissioned at the DAM-Ile-de-France Centre (BIII)

The DAM approved **extending the operational service life of the TN 75**

The AIRIX machine was transferred to the Valduc Centre

2013

Priority given to the Simulation Programme was confirmed in France's **White Paper on Defence and National Security**

President François Hollande visited the Bruyères-le-Châtel Centre

Decision taken to launch the **production phase of the Seaborne nuclear warhead (TNO)**

Parliament adopted the **2014-2019 LPM**

2014

Prime Minister Manuel Valls inaugurated the LMJ

EPURE project implemented at the Valduc Centre

2015

François Geleznikoff took over from **Daniel Verwaerde** (who became Chairman of the CEA) as Director of the DAM

President François Hollande visited the CEA/DAM Ripault Centre

2016

The TERA 1000 supercomputer was brought into service

Seaborne nuclear warhead/(TNO) commissioned on the M51 missile on SSBN

2017

The DAM approved the 2017 computing standard for nuclear warheads and laser experiments

Strategic Review of Defence and National Security

At the DAM's initiative, **the *Resistance and Deterrence* conference and the eponymous exhibition (later a touring exhibition) were held** at the Bibliothèque nationale de France

2018

The TNO programme was completed

Parliament adopted the **2019-2025 LPM**

Operational start-up of TELSITE 2, a geomechanical monitoring system for former test sites in the Pacific Ocean

The new extension to the service life of the TN 75 was approved

Test reactor (RES) divergence at the CEA's Cadarache site

The Minister of the Armed Forces, Florence Parly, gave a speech for the DAM's 60th anniversary

2019

Celebration of the 10th Epure experiment to guarantee the performance of nuclear weapons

DAM contribution to locating the wreck of the submarine Minerve, which disappeared in the Mediterranean Sea in 1968

President Macron inaugurated the loading of the core of the naval nuclear propulsion plant on the 1st Barracuda-class nuclear attack submarine 'Suffren', followed by propulsion plant divergence

1st successful fusion experiment at the LMJ

The 24th and latest French geophysical station was commissioned in Guadeloupe, contributing to the CTBT

At the initiative of the DAM, **the *Imaginaires nucléaires* [Nuclear Imaginary] conference was held** at the Bibliothèque nationale de France

2020

Vincenzo Salvetti took over from François Geleznikoff as Director of the DAM.

The DAM participated in the **1st *Fabrique Défense* event**

Address by President Macron at the Ecole militaire (Military Academy) on the defence and deterrence strategy.

DEVELOPING THE SIMULATION PROGRAMME

Computer simulation has always been used in the development of nuclear weapons. Many computations were made before carrying out any nuclear tests, not least to define measurements and calibrate diagnostics. In 1996, the transition was made from simulation to the "Simulation Programme".

Recognizing recent advances in research on simulation, the DAM began to look into ways of replacing full-scale nuclear tests with laboratory tests in 1989. Two years later, and with the approval of the French Defence Minister, this led to the launch of the PALEN programme relative to preparing for the possibility of limitations on nuclear testing.

Under PALEN, guidelines for the Simulation Programme were implemented in three key areas:

- **WEAPONS PHYSICS**: modeling physical phenomena involved in how a nuclear weapon works;
- **DIGITAL SIMULATION**: developing computer codes in liaison with the development of physical models;
- **EXPERIMENTAL VALIDATION**: carrying out specific laboratory tests to validate physical models. Unlike nuclear tests, which enable overall validation, simulation implied the "piecewise validation" of these physical models and related computer codes.

Then, at the turn of the century, the Simulation Programme entered a new phase. In September 2000, the head of the Nuclear Weapons Division, and, as such, the person in charge of the Simulation Programme, **Alain Delpuech**, was made Director of the DAM. He took over from **Jacques Bouchard**, who had, in a very short space of time, overseen the end to nuclear testing and the subsequent restructuring of the DAM.

From then on, successive Directors of the DAM were very closely involved in pushing ahead the development of the Simulation Programme. Alain Delpuech was involved until April 2007, when he was succeeded by the former heads of the Nuclear Weapons Division: **Daniel Verwaerde** from April 2007 to January 2015 (when he was named Chairman of the CEA), **François Geleznikoff** from February 2015 to December 2019, and **Vincenzo Salvetti** since January 2020.

All this means that, since 2000, the DAM has been governed by internationally recognized experts from the Simulation Programme. Year 2000 was a turning point in implementing the first milestone of the Simulation Programme, with the inauguration of the AIRIX flash radiography facility, which had completed its first qualification test the previous year.

This was one of the first cornerstones of the Simulation Programme, relative to its experimental test validation part, to be put in place.

The two large-scale facilities designed for validating the sequence of physical phenomena were brought into service in 2014, at the CEA/DAM Valduc Centre and the CESTA:

- AIRIX, TRANSFERRED TO EPURE,
- THE MEGAJOULE LASER (LMJ).

AIRIX, originally installed at the CEA/DAM Centre in Moronvilliers, was thus the first experimental machine in the Simulation Programme to be brought into service. Using X-rays, it provides instantaneous images of imploding heavy metals, enabling observation and characterization of the non-nuclear phase of operation of a nuclear weapon.

This validates models representing the initial operating phase of a nuclear weapon. This facility was built to measure, with the greatest precision, the state and the behavior of the materials used to make a nuclear weapon, under the extreme temperature and pressure conditions encountered in the hydrodynamic phase, without releasing any nuclear energy.

Within the framework of the Teutates Treaty (November 2010), France and the United Kingdom are developing joint facilities to ensure the safety and reliability of their respective nuclear weapons. This comprises the construction and joint operation of a radiographic/hydrodynamic facility at Valduc in Burgundy (EPURE), and the construction of a joint facility at Aldermaston in the United Kingdom, the Technology Development Centre.

In the case of the Megajoule Laser (LMJ), the preliminary designs were launched back in 1993, after teams at the DAM had demonstrated the advantages of a high-power laser as a means of simulating the physical dynamics of the thermonuclear phases. Thanks to the experience gained in the 1980s using the Phébus laser, significant advances had been made in understanding what is known as inertial confinement fusion, which entails recreating the conditions of a thermonuclear reaction in the laboratory.

Since the 1990s, there have been significant advances in research on high-performance computing, particularly in the area of massively parallel computers. In 2001, for example, the TERA supercomputer, with computing power of 5 teraflops, was brought into service at the CEA/DAM Ile-de-France Centre (DIF). TERA was the most powerful computer in Europe at that time. This made it possible to run the first version of the digital weapons simulator - a series of software codes used to describe as realistically as possible all the different phases of operation of a nuclear device - on the TERA computer.

Four years later, in 2005, the DAM took delivery of the TERA 10 supercomputer, with peak performance of 60 teraflops, designed by the French company Bull, in close cooperation with the CEA. Since May 2010 and the installation of the TERA 100 supercomputer at the DIF, a whole new scale of computing performance has been achieved - the petaflop scale, with the capacity to perform a quadrillion floating point operations per second. Once again, this was the first time such high computing performance had been reached in Europe.

The LMJ was preceded by a prototype called the Laser Integration Line (LIL), which started operating at the CESTA in 2002. A year later, a major milestone in the Simulation Programme was reached when the nominal energy characteristics of the LMJ were obtained on a LIL beam. Work on building the LMJ facility at a dedicated CESTA site began during the same period.

The LIL, which had been a cutting-edge instrument to perform many physics experiments relative to weapons, was closed down in February 2014. During its twelve years of service, the LIL had enabled the CEA/DAM to perform full-scale tests on all the designs and technologies developed for the LMJ.

The year 2014 was marked by the commissioning of the LMJ and the Epure facility. The first successful fusion experiment at the LMJ in 2019 marked the passing of a major milestone in the Simulation Programme to guarantee the safety and reliability of nuclear weapons, as did the celebration of the tenth French experiment at Epure that same year.

In 2010, the DAM approved the 2010 computing standard for guaranteeing nuclear warheads, used for the first time on the TERA 100 computer. For weapons designers, this was a huge leap forward in simulating the performance of nuclear warheads. From 2011, the TERA 100 supercomputer has been used with the safeguard standards for all functions of a nuclear warhead to approve the future Seaborne Nuclear Warhead (TNO).

Since 2016, the gradual commissioning of the TERA 1000, the most powerful supercomputer in Europe, will make it possible to deliver a computing performance of 25 petaflops, aiming to reach the exaflops scale by 2020. This will give a computing performance equivalent to a billion billion operations per second, in other words, a thousand times that achieved in 2010.

The objective of the Simulation Programme is, therefore, to enable France to guarantee the sustainability of its nuclear deterrent and the operation and safety of warheads without recourse to full-scale nuclear tests, in accordance with the CTBT treaty. Under these conditions, the teams of weapons designers need simulation tools to allow them to fully understand all operative areas of a nuclear device, bearing in mind that a nuclear device has to be renewed after a service life of around twenty years.

At the end of 2017, another major milestone in the Simulation Programme was reached with the approval of the 2017 simulation standard pertaining to the performance and safety of nuclear warheads. It is in fact the first standard to benefit fully from all the components of this programme, as the scope of its validation now includes experimental results obtained thanks to Epure and LMJ experiments taking place since 2014.

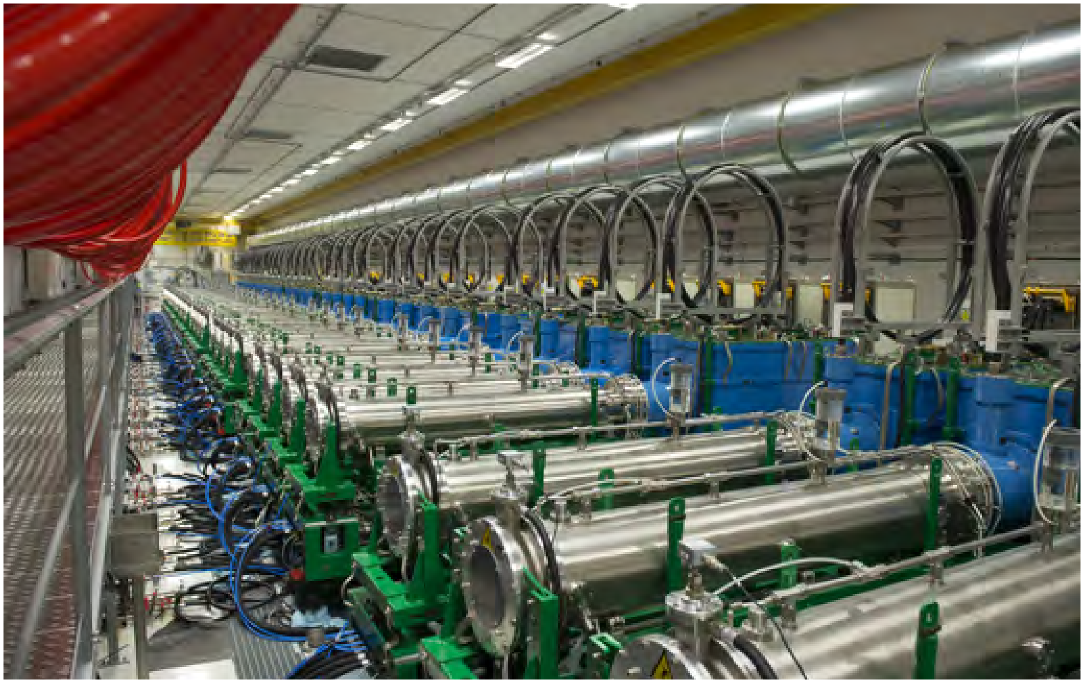
The development of the Simulation Programme and, therefore, its schedule, have been aligned from the start with the timetable for renewing nuclear warheads in both the airborne and seaborne components. In 2009, the Airborne Nuclear Warhead (TNA) became the first nuclear weapon in the world to have been guaranteed by simulation. This was followed in 2016 by the Seaborne Nuclear Warhead (TNO).

The DAM shares its activity very broadly with French industry and its industrial policy is highly original:
- first, because it acts as overall prime contractor for most of the systems under its responsibility. It enters into direct contracts, allocating DAM resources for a fair price, with the major Defence industry groups and often very innovative Small and Medium-sized Enterprises (SMEs);
- second, its budget allocation is underpinned by a work breakdown, with the DAM using its highly qualified scientists and technologists to carry out laboratory research. Once the definition phase of a product is completed, the DAM transfers the definition and processes to industry for development and production.

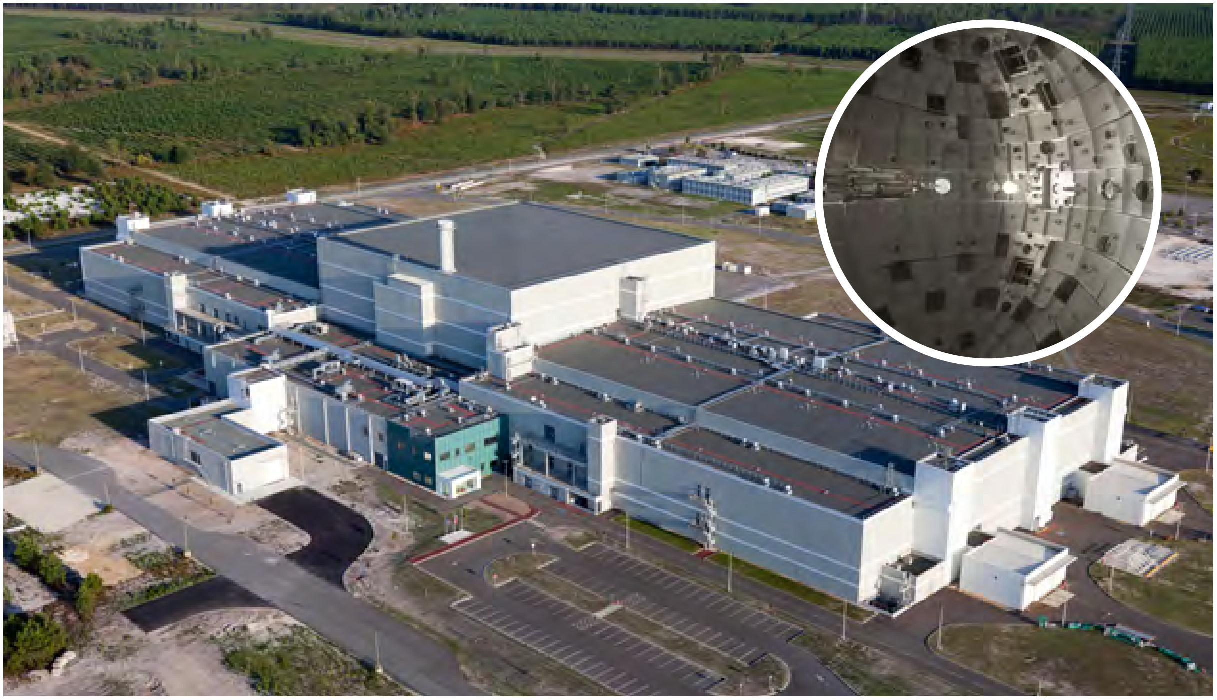
The DAM is also keen to see its centres play an active role in the local economy through their involvement in competitiveness clusters. It finds applications for research outside its specialist field, through technology transfer to industry and by filing numerous patent applications.

↑ Epure Building

EPURE – VALDUC



← AIRIX machine - Accelerator cells



MEGAJOULE LASER (LMJ)-CESTA

↑ Building and experimental chamber

← Laser lines

TERA 100 computer brought into service at the DIF Centre in 2010


Bull
cea
bullx
TERA 100

THE CEA/DAM'S OPENING POLICY

In 2001, the French Ministry of Defence adopted a new approach in opening the Simulation Programme up to civil research centres and industry, etc., thereby making its computing resources (TERA), and its high-power laser experimentation resources (the LIL and the LMJ) available for use by the wider national and international scientific community.

In fact the high-power lasers were made available to the scientific community at a very early stage in France, in 2005, only three years after the LIL facility had been commissioned. At around the same time, the Aquitaine Regional Council, the French Ministry of Research and the European Union had implemented another joint initiative, the PETAL (Petawatt Aquitaine Laser) project. This project aimed to construct a high-energy high-power laser, generating kilojoule-class laser pulses. Officially launched in 2005 and coupled to the LMJ, the PETAL laser facility overcame the Petawatt power barrier in May 2015 (achieving 1.2 PW in 0.7 picosecond), making it the most powerful high-energy laser in the world.

The first campaign to open up the LMJ-PETAL project on an international scale was carried out in December 2017; the conditions for carrying out the experiments are in line with the expected characteristics, as well as with the accuracy required in terms of synchronizing the LMJ and PETAL pulses on the target.

In the field of high-performance computing, alongside the Computing Centre exclusively dedicated to military applications (TERA), the DAM's expertise has also been available for academic researchers and industry since an early stage. This policy of openness materialized in 2002, with the TERA computer being made available for genomics calculations carried out by the Université d'Evry. The idea was to develop a High-Performance Computing (HPC) "centre of excellence".

It was with this in view that, in 2003, the CEA's Research and Technology Computing Centre (CCRT) opened at a dedicated site at the DIF Bruyères-le-Châtel centre. The CCRT is intended to provide academic researchers and industry with CEA's capabilities in high-performance computing. An extremely broad range of applications has been studied ever since, including nuclear reactor safety, materials behaviour, electronics, aeronautics, climate change and medicine.

Another initiative developed since 2004 as part of this policy of openness has been the Ter@tec project undertaken jointly by the Essonne General Council, local authorities and the DAM Ile-de-France Centre. Ter@etc aimed at bringing together key players in research, higher education and in the field of high-power computing (and, therefore, digital simulation).

The ultimate aim is to create an ecosystem, a networking system for HPC technology, encompassing France and Europe. The Ter@tec technology park is now home to the CEA's Very Large Computing Centre (TGCC), inaugurated in 2010, and a university campus attracting students on Master programmes specializing in particular in high-performance simulation and modeling. The TGCC houses the CCRT, which is open to the French civil research and industry community, and the Curie supercomputer, which is open to users from across Europe.

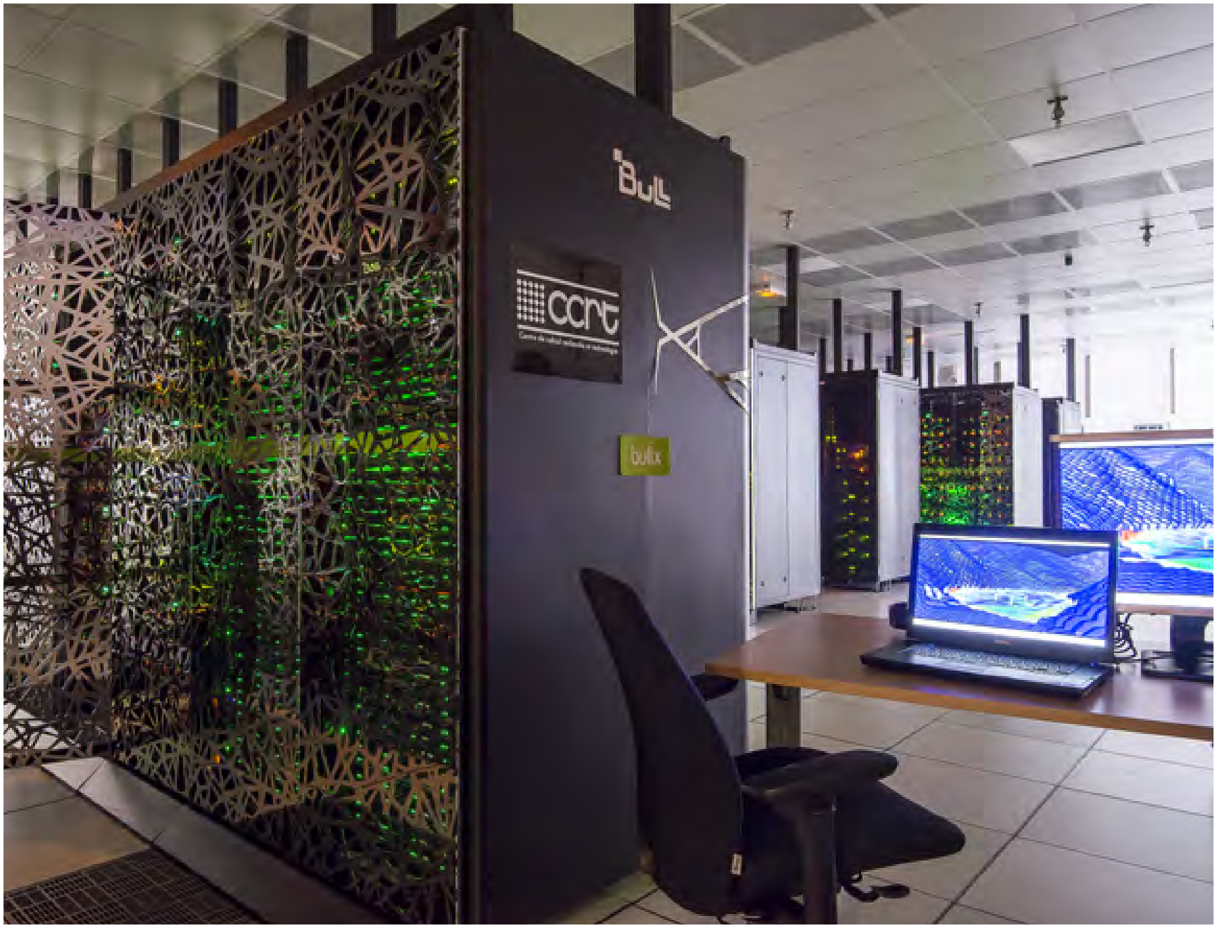
↓ **Laser Integration Line-CESTA**

↑ **The PETAL Laser at the LMJ**

↑ **The Tsunami Warning Centre-DIF**

↑ **Ter@tec-DIF**

←↑The TGCC high performance computing centre and its lecture theatre-DIF



↑ The Airan supercomputer at the TGCC

THE DAM, A KEY PLAYER IN FRANCE'S DEFENCE SYSTEM

With the end of full-scale nuclear tests and the transition to simulation, the CEA/DAM instigated changes in its working methods and its organization. This also entailed a new positioning for the CEA/DAM within the French defence system. This operated on two fronts: the withdrawal of the armed forces in their key role in managing the logistics for nuclear tests, and a new role for the Director of the DAM within the defence system.

Ensuring the technical credibility of nuclear weapons simulation now rested entirely on his shoulders. He alone is responsible, and therefore accountable, for guaranteeing the operating performance and safety of nuclear weapons to the French President. Indeed, unlike the regular deployment of vectors (aircraft and SSBN) and missile testing it was no longer possible to conduct full-scale nuclear tests, which, until then, had confirmed the success of nuclear weapons testing.

In 2002, the Director of the DAM was invited to sit on the Nuclear Weapons Council (*Conseil des Armements Nucléaires*), a major change since, before this, he only had occasional meetings with the President. This was made official in 2009, when a decree institutionalizing the Director of the DAM's membership of the Nuclear Weapons Council was passed.

As an example of this new responsibility, **Daniel Verwaerde**, then Director of the DAM, worked with his British counterpart on drawing up the Lancaster House Treaty, signed in 2010, between the French and UK governments and relating to developing shared radiographic and hydrodynamics facilities (Teutates-Epure programme). The DAM thus became a key player in the definition and application of France's nuclear diplomacy.

This key role, working closely with political decision-makers, is directly related to the new status acquired by the DAM within the French defence system, following the ban on nuclear tests and the development of the Simulation Programme.

President Jacques Chirac on a visit to the DAM in 2006
Left to right: Michèle Alliot-Marie (Defence minister), President Jacques Chirac and Alain Delpuech (DAM)

DAM's 60th Anniversary in 2018
Left to right : François Geleznikoff (DAM) and Florence Parly (Defence minister)

↓ *Rafale* aircraft

↑ **Nuclear-powered ballistic missile submarine**

← **Cone tent and aqueous foam used for an explosive containment exercise at the Gramat Centre, 2013**

↑ **Counter-terrorism exercise at Saint Fargeau**
→ **metro station, Paris, 2008**

DIRECTORS OF CEA'S MILITARY APPLICATIONS DIVISION

Albert BUCHALET

March 1955 - September 1958 (BEG)
September 1958 - April 1960 (DAM)

Jean VIARD

May 1970 - March 1972

Jacques CHEVALLIER

September 1972 - June 1985

René COTY (1953-1959)

Charles de GAULLE (1959-1969)

Alain POHER (interim government, 1969)

Georges POMPIDOU (1969-1974)

Alain POHER (interim government, 1974)

Valéry GISCARD D'ESTAING (1974-1981)

François MITTERRAND (1981-1995)

Reggane
(1960-1961)
4 atmospheric tests

In Ecker
(1961-1966)
13 underground tests

Mururoa and Fangataufa
(1966-1974)
46 atmospheric tests

Mururoa and Fangataufa
(1975-1996)
147 underground tests

Jacques ROBERT

May 1960 - April 1970

Robert CAMELIN

March 1972 - August 1972

Alain VIDART

July 1985 - April 1988

Roger BALÉRAS

April 1988 - July 1994

Alain DELPUECH

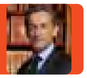
September 2000 - April 2007

François GELEZNIKOFF

February 2015 - December 2019

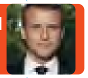
Jacques CHIRAC
(1995-2007)

Nicolas SARKOZY
(2007-2012)



François HOLLANDE
(2012-2017)

Emmanuel MACRON
(Since 2017)



Simulation Programme

(Since 1996)

Jacques BOUCHARD

August 1994 - August 2000

Daniel VERWAERDE

April 2007 - January 2015

Vincenzo SALVETTI

Since January 2020

DESIGN AND PRODUCTION

HISTORIAN: **Dominique MONGIN**

IMAGE RESEARCH and TECHNICAL REVISION: **CADAM and William DELAHAYE**

GRAPHIC DESIGN: **JPM Partner**

TRANSLATION: **Provence Traduction; Océane TRANCHEZ**

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ECPAD: Pages 29 (top left) - 44 - 45 (top) - 48 - 54 - 60 (right) - 63 (top) - 67 (right) - 70 - 78 (top) - 81 (left) - 82 - 83 - 132 (top)

IGN: Page 31

Philippe STROPPA: 124 (bottom) - 128 (bottom)

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