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Technopolitical Regimes

Before I began interviewing engineers about their involvement in the development of nuclear power, I expected our conversations to be dry, technical affairs in which these men would describe their small corner of reactor design and indignantly deny that their work had political or social components. My expectation arose from two sources. First, much scholarship argues that scientists and engineers expend a good deal of energy denying the political, social, or cultural, dimensions of their activities. Donald MacKenzie demonstrates this point particularly forcefully in regard to the engineers involved in the development of nuclear missile guidance in the United States.[1] Second, many American commentators argue that nuclear technology has been "depoliticized" in France. By this they mean that parties across the political spectrum agree that the nation should pursue both nuclear power and atomic weapons, and that there is little or no public debate about these choices.[2] Anticipating, then, that direct attempts to address the political aspects of technological work would induce suspicion and mistrust, I resolved to begin my interviews by asking about the "scientific and technical" decisions in which my informants had participated. I hoped that a discussion of technical details would lead, discreetly and indirectly, to comments about the political and social aspects of nuclear engineering.

My first appointment was with a man who had been a project engineer for six gas-graphite reactors. By the time I met him, he was a high-level manager with an enormous, sumptuously furnished office in EDF's headquarters. I tried hard not to feel intimidated as I sat down in front of his vast, polished wood desk. In hopes that challenging gender stereotypes would counterbalance the disadvantage I felt as a young woman interviewing a much older male expert, I had worn a suit and tie. I quickly established my technical credentials, reaffirming (as I had already explained in the first paragraph of my query letter) that I had a degree in physics from MIT, the "Polytechnique de l'Amérique."[3] Thus armed, I began my introductory spiel: I wanted (I explained) Monsieur le directeur to tell me about the scientific and technical decisions in which he had taken part during the 1950s and the 1960s. Imagine my surprise when Monsieur le directeur slapped his hand on the desk, leaned toward me, glaring, and roared: "But Mademoiselle! These were not scientific or technical decisions! They were economic decisions! Political decisions!"

Over the next few years, this encounter became the paradigmatic story of my research. In one respect, it was unique: this particular man turned out to be an unusually colorful character who enjoyed emitting shocking statements. None of the other men I interviewed made such bald declarations. A few did deny that their work had political dimensions. Yet most of them appeared to assume that politics was a normal part of their job. In another respect, then, this incident provided only the most explicit example of a widespread belief among these engineers in the necessary interweaving of technology and politics.

In the previous chapter I showed how this belief formed the central premise of elite state technologists' efforts to shape national discourse about France's identity and future. But Monsieur le directeur's exclamation suggests that the deliberate interweaving of technology and politics ran much deeper than this public discourse. In the nuclear program at least, it permeated all levels of development, from the interactions between nuclear leaders and government officials to the artifacts and practices of reactor design.

In this chapter, in order to explore the multiple facets of this interweaving, I develop the notion of *technopolitical regimes*. The two regimes I discuss were grounded in state institutions, one at the Commisariat à l'Energie Atomique (CEA), and the other at Electricité de France (EDF). They consisted of linked sets of individuals, engineering and industrial practices, technological artifacts, political programs, and institutional ideologies acting together to govern technological development and pursue *technopolitics* (a term that describes the strategic practice of designing or using technology to constitute, embody, or enact political goals). As I noted in the introduction, the "regime" metaphor is meant to evoke the tight relationship among institutions, the people who run them, their guiding myths and ideologies, the artifacts they produce, and the technopolitics they pursue. It also conveys the notion of prescription: as I will show, each regime aimed to prescribe policies, practices, and visions of France's future. Finally, "regime" captures the dynamics of power: even within the institutions that housed them, these regimes were subject to negotiation and contestation.

These analytic points will become clearer as we see the two technopolitical regimes in question take shape. In the present chapter I will discuss each regime in turn. From the mid 1940s to the mid 1950s, the nuclear program belonged to the CEA. I will begin with this institution, describing the emerging dominance of a nationalist ideology within it. This was simultaneous with, and closely linked to, the choice of the gas-graphite design for the CEA's first industrial-scale reactors. A nationalist technopolitical regime developed within the institution. As the CEA began to build its gas-graphite reactors, this regime grew stronger and more established, articulating increasingly ambitious goals not just for the nuclear program, but for French industrial development more generally.

Next I turn to EDF. I briefly situate its creation in the wave of postwar nationalizations and discusses competing views of the meaning of nationalization in the utility. Because EDF devoted its first decade primarily to building ordinary power plants, I skip over that period and move straight to its first involvements with the CEA and nuclear power. The nationalized technopolitical regime that emerged to govern nuclear development within EDF situated itself at the intersection of two emerging technological systems: the fast-growing electric power network and the budding nuclear program.

Each regime developed its own reactor site, but limited resources forced them to collaborate on both. This collaboration was fraught with conflict, because each regime sought to mold its reactors into components of its technopolitics. Comparing the design and the industrial contracting process of the reactors built by the two regimes reveals two dimensions of the technopolitics. The first involved French nuclear policy. The CEA's reactors produced weapons-grade plutonium at a time when official government policy had not yet decided in favor of a French atomic bomb; they thus constituted the nation's de facto military nuclear policy. EDF's regime, meanwhile, positioned its reactors in deliberate counterpoint to the CEA's technopolitics: it wanted its first reactor at Chinon to constitute the first step toward an economically viable nuclear *energy* program. The second dimension of these technopolitics involved French industrial policy. Should the state promote national "champions" in different industrial sectors, which ultimately might mean creating consortia of private companies within the same sector? Or should it, on the contrary, promote competition among companies in order to force them toward higher standards of technical excellence and economic efficiency?

And which route would best enable French companies to export their technologies and compete successfully in the international market? In the mid 1950s the CEA's regime chose the first route when organizing industrial contracting for reactor construction, while EDF's regime chose the second.

The Creation of the CEA

The Commissariat à l'Energie Atomique began its life as the ultimate post-Resistance institution, the product of a common vision of communist wartime resistants and Charles de Gaulle.[4] The communist physicist Frédéric Joliot-Curie had spent the war in France as a member of the Resistance, attempting to hide the results of French nuclear science from the German occupiers and helping to smuggle crucial nuclear materials out. In these efforts he had the support of Raoul Dautry, the minister of armaments before the German invasion. At the war's end, the two men easily convinced de Gaulle that a nuclear program would both elevate France's stature in international politics and accelerate its industrial and economic recovery. Following de Gaulle's recommendation, the National Assembly quietly approved the creation of the CEA in October 1945. The agency's stated mission was to "pursue scientific and technical research in the view of using atomic energy in the various domains of science, industry, and national defense."[5] Joliot-Curie and Dautry both argued—and de Gaulle agreed—that the CEA should be protected from the whims of ministerial politics. Yet it needed to remain "very close to the government because the fate or the role of the country might be affected by the development of [atomic energy]."[6] The statutes therefore specified that the CEA was accountable only to the prime minister, and that it would not be subject to the same financial controls as other state institutions.

The institution's leadership structure reflected an ambiguous marriage of science and politics: it was a dyarchy headed by a scientist who carried the title of High Commissioner and a professional administrator who carried the title of Administrator General. The two men would share power equally. Not surprisingly, de Gaulle appointed Joliot-Curie and Dautry to these two posts. The CEA's steering committee included several of the institution's top scientists, a number of government-appointed administrators from a variety of ministries and other state institutions, and a military general. Despite this military presence and the mention of "national defense" in the CEA's creation ordinance, official government policy stated that France would limit its atomic endeavors to peaceful ends.

After de Gaulle stepped down from power in 1946, the government lost interest in the CEA. Parliament passed a new constitution, and the Fourth Republic began. The new government was headed by a rapid succession of prime ministers (twenty different men over thirteen years), who initially focused on the pressing concerns of national reconstruction. Left to their own devices, scientists dominated the CEA's operation during its first five years. They concentrated on conducting fundamental research in nuclear physics and chemistry, developing large-scale experimental equipment such as reactors and accelerators, and prospecting and mining uranium. The steering committee agreed that these activities constituted the basic building blocks of any nuclear program, especially since the Americans and the British displayed no intention of sharing their research results or their raw materials. This agreement persisted as long as no one evoked more ambitious goals.

As the Cold War intensified, however, successive governments found Joliot-Curie's communist affiliations increasingly embarrassing. In 1949 the Soviets successfully tested their first atomic bomb. Shortly afterward, the British convicted the scientist Klaus Fuchs of passing nuclear secrets to the Soviets. Tensions were already high, therefore, when Joliot-Curie declared in April 1950 that he would never build an atomic bomb, because such a weapon could only be aimed at the Soviet Union and would therefore help to precipitate another world war. Speaking out against nuclear weapons per se did not conflict with the government's position: spokesmen repeatedly declared that France cared solely about peaceful applications of atomic energy. But Joliot-Curie's reference to the Soviet Union was unforgivable. The United States protested the presence of a communist at the head of such a strategically sensitive institution. Prime Minister Georges Bidault dismissed Joliot-Curie in late April. Nearly a year passed before Joliot-Curie was replaced by another eminent (but less vocal) scientist, Francis Perrin.[7]

The interval gave the non-scientists on the CEA's steering committee the opportunity to increase their influence within the institution. René Lescop, a *polytechnicien* whom Dautry had appointed to the position of secretary-general, seized the moment forcefully. In January 1951 he and Dautry spearheaded a formal institutional reorganization which subordinated scientific authority to administrative authority. Both men had privately expressed enthusiasm for a French bomb, so the scientists recognized that this move could have national political implications. In August of that year, Dautry died, leaving Lescop as the highest-ranking administrator on the steering committee.

The Emergence of a Nationalist Technopolitical Regime

That same month, the CEA acquired an important political ally: the young parliamentary deputy Félix Gaillard, newly appointed as state secretary for atomic energy.[8] Gaillard's position placed him on the CEA's steering committee, and it quickly became clear that he intended to push an ambitious program for the agency, one that fit better with Lescop's ideas than with those of the scientists. Convinced that France's future lay in the strength of its nuclear program, Gaillard urged the committee to draft an ambitious five-year plan for the development of atomic energy—one that would seduce Parliament by promising material benefits in the near future. It would be easier, he said, to justify a 20 billion franc plan that included developing atomic energy on an industrial scale than a 3 billion franc[9] plan devoted only to basic research. Atomic technology appeared vital to France and its dwindling empire. "The use of atomic energy can command the future of France (and of the French Union)," Gaillard declared confidently. "Our country's lack of industrial capacity is increasingly dramatic, and inasmuch as atomic energy can provide a solution in a few years, the CEA's future budget is a national issue."[10]

Perrin and other scientists expressed doubts about whether the CEA had the scientific and technical ability to carry out an extensive program. They would have preferred to concentrate on education in order to build a solid base of trained scientists and engineers.[11] But François de Rose of the ministry of foreign affairs, and other administrators, supported Gaillard. The CEA should aim high, he said. France currently led the second-tier nuclear nations, but (he argued) this might change if Germany decided to start a large-scale nuclear power program. France's future leaders would thank the CEA for having the foresight to plan extensive nuclear development.[12]

The scientists eventually agreed to the principle of a large-scale reactor program. This raised an important question: What sort of system should the CEA choose? "Primary" reactors, such as those built by the British, ran on natural uranium, of which France had plenty, largely thanks to its colonial territories. "Secondary" reactors, developed in the United States, ran on enriched uranium.[13] But enriched uranium was not for sale anywhere, so the CEA would need to build an enrichment plant—something it had neither the time nor the knowledge to do. Primary reactors, meanwhile, could produce both plutonium and electricity. And Bertrand Goldschmidt, who had spent the war in Canada working on the

Manhattan Project, already knew how to extract plutonium from irradiated uranium.[14]

In principle, plutonium could be used in secondary reactors—though no one had yet managed to do so. The metal had, however, proven highly suitable as bomb fuel. Some scientists worried that building plutonium-producing reactors would effectively constitute the first step toward a French bomb. They feared that producing the fuel would, at the bare minimum, whet the military's appetite.[15] The military representative on the steering committee had already expressed his personal interest in the atom bomb.[16] Further, asked the scientists, wouldn't building plutonium reactors alarm the United States?[17] Gaillard's supporters dismissed such objections. They reiterated that plutonium could be used as reactor fuel, and they reminded the committee of France's urgent need for energy sources. Without further ado, the committee settled on primary reactors. And without specifying the end use, it set a production goal of 15 kilograms of plutonium within five years.[18]

Having made this decision, the committee next had to pick a moderator for its reactor. The choice was between graphite and heavy water.

Natural uranium contains two isotopes of uranium: U_{238} and U_{235}. Fission occurs when a neutron hits a U_{235} atom, causing its nucleus to split and liberating a great deal of energy as well as more neutrons. Some of these additional neutrons are absorbed by other U_{235} atoms, causing more fission. With enough uranium piled up (what is known as critical mass), this fission reaction will "go critical" and be self-sustaining. Other neutrons, absorbed by U_{238} atoms, will not cause fission. Rather, upon absorbing a neutron, a U_{238} atom becomes U_{239}, which eventually changes into Pu_{239}—weapons-grade plutonium.

The committee members knew that, in order to split a U_{235} atom successfully, a neutron must be traveling at a speed lower than that at which it was released. Therefore a moderator was required to slow down the neutrons. The ideal moderator would not itself absorb any neutrons. Finally, a coolant was needed in order to extract the heat from the reactor core.

At the time of the steering committee's September 1951 meeting, the CEA had already built experimental heavy water reactors.[19] Physicists preferred heavy water as a moderator because it absorbed fewer neutrons. But heavy water could be made only by electrolysis, which itself required electricity. A heavy water plant seemed complicated and expensive to build, while the French company Péchiney already manufactured graphite. Such were the official reasons for choosing graphite over heavy water as a moderator.

An additional reason, however, was suggested by an engineer who worked on the early gas-graphite designs. Many of those who had worked on the experimental heavy water reactors were communists. Some had been dismissed along with Joliot-Curie. Since the plutonium produced by the first industrial-scale reactors might go into a future French bomb, some committee members wanted an easy way of excluding communist scientists and technicians from the new projects. Not picking the technology in which they had experience greatly facilitated this task.[20]

The CEA steering committee thus settled on a five-year plan for 1952–1957 that committed the CEA to building two reactors, powered by natural uranium and moderated by graphite. The plan also included a factory to extract plutonium from the spent uranium fuel that would emerge from the reactors.

Pleased with these goals, Gaillard took the plan to Parliament for approval. Because it conferred prestige and glory, he argued, France needed nuclear energy. In one radio broadcast, he warned that "those nations which did not follow a clear path of atomic development would be, 25 years hence, as backward relative to the nuclear nations of that time as the primitive peoples of Africa were to the industrialized nations of today."[21] Without nuclear technology, France's global position might move from that of a world empire to that of a backward, colonized nation. Gaillard reminded his fellow deputies of the nation's weakness in energy resources, and noted that expanding the nuclear program meant developing France's industrial base and ensuring its future energy supply.

Deputies on both ends of the political spectrum were clearly persuaded of the symbolic significance of nuclear technology. They used this symbolic value to reenact an increasingly familiar Cold War debate over the position of French communists. One right-wing deputy expostulated that the persistence of communists in the CEA was "scandalous, for it subordinates the work of an organ where the atomic future of our country is being worked out to Moscow's control."[22] Still reeling from Joliot-Curie's dismissal, meanwhile, communist deputies suspected Gaillard of concealing military goals. They demanded that the plan explicitly state that France would never build an atomic bomb. But the other deputies refused to vote for this amendment—not because they were prepared to approve a French bomb, but because they did not want to make any concessions to the communists. Someday, one right-wing delegate argued, France might need a bomb to "safeguard her independence and security."[23] He worried that on that day the communists remaining in the CEA might prove more loyal to their former leader (Joliot-Curie) than to their nation. Might not the plutonium eventually be used in a bomb, and shouldn't all communists be removed from the CEA as a precaution against that day? To calm anxieties, Gaillard played both ends against the middle. He agreed that France should not rule out a bomb a priori. He reassured the right that plutonium production would take place in a separate division of the CEA and hence be subject to special security measures. At the same time, he insisted that his plan was in no way directed toward military ends: the cost of a single bomb, he claimed, represented ten times the funds he had requested.[24] (This cleverly avoided the question of whether the proposed development would contribute to a bomb.) Appeased, Parliament approved a budget of 37.7 million francs for the CEA in July 1952.[25]

Plutonium was thus represented, not as bomb material, but as a lifesaving fuel for the energy-starved nation. Even Antoine Pinay, the French president, understood the element in this way.[26] But the CEA steering committee had chosen the gas-graphite design knowing that it could yield weapons-grade plutonium. Beginning in November 1951, the agency's new Administrator General, Pierre Guillaumat, ensured that the reactors would do exactly that.

Guillaumat had graduated from the Ecole Polytechnique in 1931 and joined the Corps des Mines. He had begun his career in the far reaches of the French empire, first in Indochina and then in Tunisia. He had become a friend and ally of de Gaulle during the war, serving the Resistance as a secret agent.[27] After the liberation he had been appointed to direct France's energy policy and fuel supply.

Guillaumat was the quintessential "man of action." He held deep convictions about the necessary relationship between technological prowess and national radiance. According to one *polytechnicien,* Guillaumat's "extraordinary force of conviction, his charisma, his incomparable talent for building those modern cathedrals that were the great projects of national independence, won him the admiration and respect of the entire community of state engineers."[28] His wartime record proved his capacity to make tough choices under dire circumstances and gave him useful talents. His experience in the secret service, for example, convinced him that "actions taken behind the scenes [were] often more effective than those taken on stage."[29] He applied this lesson extensively during his directorship of the CEA. While successive government leaders continued to proclaim France's interest in a solely peaceful atom, within the CEA Guillaumat aggressively pushed the production of weapons-grade plutonium as well as other technologies essential for making atomic bombs.

As one of his first moves, Guillaumat created a new division—the Direction Industrielle—to direct the reactor construction projects. He placed Pierre Taranger, another *polytechnicien*, at its head. Guillaumat and Taranger made it clear to their top engineers that they had to build a plutonium production facility as quickly as possible. In less than five years, both the first reactor, G1 (heavily modeled on the American Brookhaven reactor, which Taranger had visited[30]), and the plutonium extraction factory were operating at the CEA's new Marcoule site in southern France. Studies for G2—a second, larger, more innovative reactor—were underway.

Parliament had approved the Gaillard plan in part because it supposedly represented the first step in a more extensive nuclear *energy* program: the plutonium produced in these reactors would fuel other, future reactors, and in the meantime Marcoule could serve as a prototype. Yet no one even mentioned extracting electricity from G1 until its design was almost finalized. Then Pierre Ailleret, the head of EDF's research division and a member of the CEA's steering committee since 1950, suggested appending a 5-megawatt plant to G1.[31] Questions had already arisen over which institution would provide France with nuclear energy: EDF, the nation's designated electricity supplier, or the CEA, the official guardian of all things nuclear. For Ailleret, G1 provided the perfect opportunity to involve an EDF team in the nuclear adventure. The rest of the steering committee consented. Perrin and other scientists apparently hoped that an alliance with EDF would veer the CEA away from the military atom.[32] Generating electricity at Marcoule suited Guillaumat and his allies because it strengthened their public claims that these reactors represented the first step in producing nuclear electricity; in house, however, they stressed that electricity generation should not interfere with plutonium production. With this same caveat, the steering committee also let EDF build a 25-megawatt plant for G2.[33]

The decision to develop gas-graphite reactors together and the arrival of Guillaumat signaled the beginning of a new technopolitical regime in the atomic energy commission. This regime strengthened the ideological principles upon which the CEA had drawn since its inception: the importance of nuclear technology in ensuring French grandeur, the significance of independent energy sources for national autonomy, and the primacy of nuclear expertise. Under Guillaumat's regime, however, this ideology had added dimensions. Communists became increasingly unwelcome in the CEA, and in early 1952 they fell victim to another wave of dismissals when Guillaumat reorganized the agency. In the unstable political climate of the mid 1950s, Guillaumat took full advantage of the CEA's vaunted autonomy from ministerial control, using more and more of the institution's resources to pursue the military atom behind the scenes. He thereby embraced the spirit of the CEA's original statutes as expressed by their author:

> —if it is a question of mining research in the colonies, the Commissariat . . . *is* the Ministry of Overseas France;
>
> —if it is a question of mining concessions in France, it is the Ministry of Industry;
>
> —and, if it were a question of manufacturing atomic weapons, it would be the Ministry of National Defense.[34]

The CEA's new regime expressed an ideology that saw national grandeur first and foremost in terms of military technological prowess. It valued institutional autonomy and nuclear expertise, and it upheld a vision of nationalism that excluded communists. Its primary goal, articulated by Guillaumat, had become to make a French atomic bomb.

Had the CEA merely lobbied in favor of a French bomb, I would not be justified in identifying this constellation of ideologies and people as a technopolitical regime. But Guillaumat and his men did not stop at lobbying. Instead, they directed the design of reactors that would effectively enact their policy goals. In the process of constructing these reactors, they also developed additional goals pertaining to French industrial policy. The scientists and engineers who worked on the gas-graphite program explicitly and consciously used political as well as technical criteria to make design and contracting choices. Their reactors emerged as hybrids of technology and politics. To understand how this process worked, let me examine G2, Marcoule's second and most innovative reactor.

The G2 Reactor: Developing a Nationalist Technopolitical Regime

One of the most important issues faced by Taranger and Guillaumat in directing the G2 project was the relationship between the CEA and private industry. Until Marcoule, the CEA had been primarily a research institution. It had no experience with large-scale construction, nor did it have the knowledge, the personnel, or the mandate to engage in construction projects directly. It therefore had to contract reactor construction to private companies. How should this contracting relationship be structured?

Taranger and Guillaumat believed that the relationship between the CEA and its contractors had prescriptive potential: it could set an example for other large-scale industrial developments. More was at stake than just the reactor project, important though that project was. They believed that the prestige of nuclear development gave them the opportunity to shape the structure of French industry (and hence the nation's future) more generally. French companies, they argued, should not waste time or resources competing against one another. In order to stand up to increasingly large foreign companies, French industry needed to consolidate its resources and develop its strengths. Accordingly, the CEA leaders espoused what came to be known as the "policy of champions."[35] This involved hand-picking a single company to design each major reactor component, without issuing a request for bids. Initially they took this approach out of necessity as much as out of conviction: many companies did not initially want to become involved in nuclear development. The CEA engineer in charge of coordinating the construction of G1 and G2 remembers:

> . . . as soon as Taranger became the industrial director, he made the full rounds of French industries . . . and asked them, "are you interested?" When he finished his rounds, during which he must have met with something like fifty large industrialists—all the big names of French industry, in every sector—he found four big firms who wanted to work. These were Schneider, Alsthom, l'Alsacienne, and Rateau. That's it, the end. The others had said "no, maybe, okay but." One can't say that they were all rushing toward the door at the beginning.[36]

Taranger and Guillaumat felt that the "policy of champions" made it easier to convince private companies to participate in a venture that would not yield large immediate profits. Building G2 wouldn't make companies rich, but it would give them know-how, confidence, and prestige that they would be able to use in the future to export technology. Ultimately, then, this policy would enhance France's industrial base in the short term and its economy in the long term. The "policy of champions" thus constituted one prescriptive dimension of the CEA's technopolitical regime.

Under Taranger's guidance, the CEA's Direction Industrielle grouped the chosen companies into a consortium and placed the Société Alsacienne des Constructions Mécaniques (SACM), itself a conglomerate of electrical and mechanical engineering companies, at the head. The CEA signed a contract with the SACM, which subcontracted to the other companies and coordinated the overall design and construction process of G2. The design process was a cooperative effort: after CEA engineers defined the function of a reactor component, industrialists would propose an initial design, which would then be discussed in a series of meetings. Two sorts of such meetings occurred: meetings between a CEA team and a single company to talk about a specific component, and large monthly meetings grouping together representatives of all the CEA teams, all the companies, and EDF when relevant.[37] Guillaumat and Taranger wanted the reactor to be built quickly so that it could start producing plutonium.[38] This decision-making process had the short-term advantage of producing solutions that industry was capable of building. Left to their own devices, said an EDF engineer present at these meetings, CEA teams would have envisioned complex solutions beyond the means of French industry, and the deadline would never have been met. Even so, he added, the solutions chosen were often costly and cumbersome.[39]

Compared to time, however, cost was a secondary consideration for the CEA, and in the case of the G2 reactor EDF had little input. From the beginning, CEA engineers made it clear that EDF had to play a subordinate role. It had also signed the main contract with the SACM, but its "energy recuperation installation" was considered an auxiliary device to the reactor. Thus, although EDF engineers sat in on the monthly meetings with industry, they were not expected to voice concerns over the design of their installation. Industry had to give the CEA contracts priority over those signed with EDF.[40] Furthermore, EDF engineers did not always know about design changes that had a direct impact on their work.[41] This meant that no part of the reactor itself was designed to optimize the production of electricity.

The "nuclear" part of the reactor, then, took priority over the "classical" part.[42] The "best" companies were chosen to build the trickiest, "most nuclear" parts, with little regard for cost. Contracts signed for such parts were contracts of principle: the company agreed to build a device that would perform certain functions, but the specifications were not fixed ahead of time. In contrast, the "less nuclear" parts of the reactor, such as the "energy recuperation installation" or the prestressed concrete vessel, were covered by contracts detailing both specifications and cost.[43]

What sort of reactor emerged from all this?

Figure 2.1 depicts the design of G2. Most of the reactor was housed in a large building designed to protect its contents from the vagaries of the weather. (The Marcoule reactors did not have containment buildings.) The core, contained in the large cylinder, was made up of a stack of graphite bars piled in horizontal layers. Distributed through this pile were 1200 channels, into which the uranium fuel was loaded. The uranium came in small cylindrical rods hermetically encased in aluminum cladding. Each channel could hold as many as 28 of these uranium fuel rods (figure 2.2). When enough rods were loaded into the reactor, it went critical, setting off a self-sustaining fission reaction. The fission taking place inside the rods liberated a great deal of heat, which the

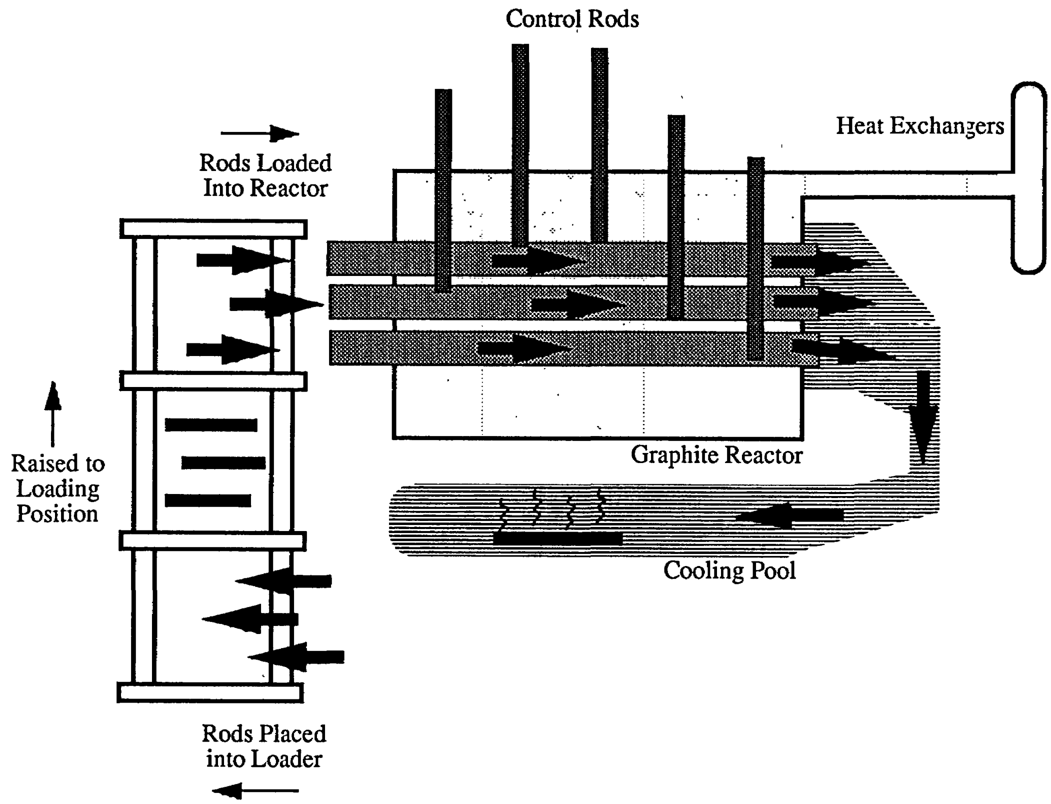

Figure 2.1
Schematic diagram of G2 (not to scale). Source: *Bulletin d'Informations Scientifiques et Techniques du CEA*, no. 20 (1958). Drawing by Carlos Martín.

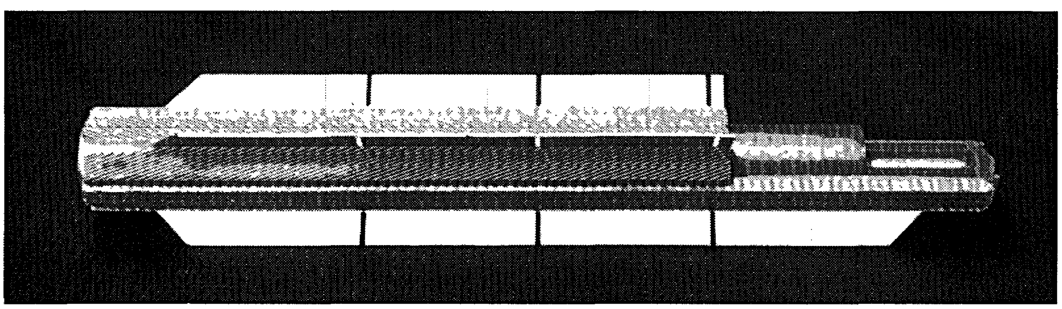

Figure 2.2
A uranium fuel rod with aluminum cladding. This particular rod is a 1968 model that was used in EDF's Chinon reactors, but its design is close to that of the G2 rods. The uranium is cast in a cylindrical mold in the center. The aluminum cladding has grooves on the outside to facilitate the even circulation of cooling gas. Photograph by F. Roux, 1968. Source: EDF Photothèque.

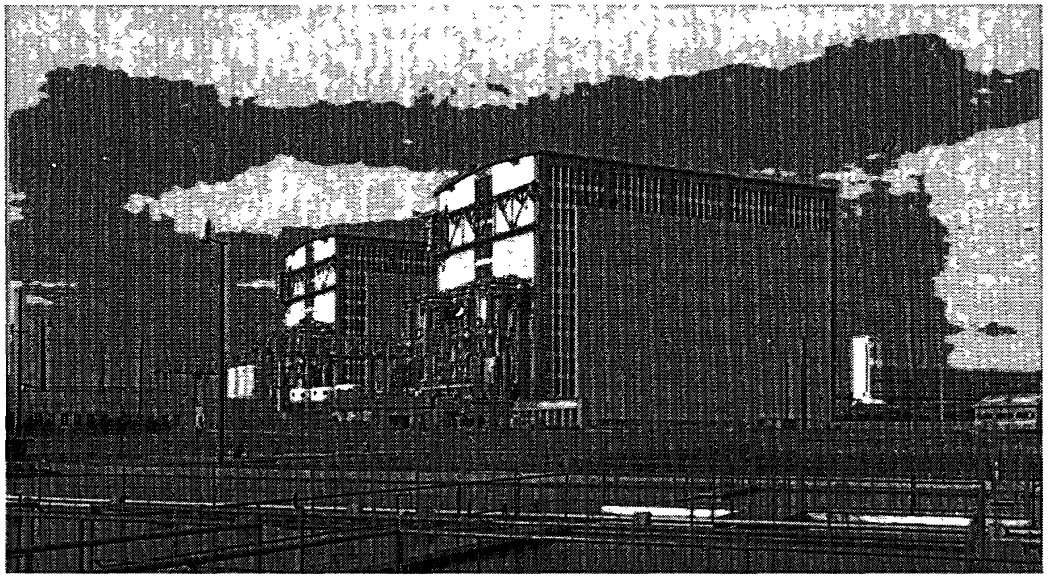

Figure 2.3
G2 and its twin, G3, in 1960. The four heat exchangers are lined up along the back wall of each building. Source: CEA/MAH/Jahan.

cladding absorbed. Carbon dioxide gas, entering the channels through openings on the back face, flowed around the rods and cooled the reactor by absorbing this heat. Upon leaving the core, the coolant traveled to the "energy recuperation installation" where the heat was converted into electricity.

Even this quick overview of G2 reveals that generating electricity was secondary. The "energy recuperation installation" stood outside the building that housed the reactor, both physically and symbolically removed from the fission reaction. In order to show in greater detail how the political agenda of plutonium production took precedence, I will concentrate on two aspects of G2's design: the loading and unloading of fuel in the reactor and the "energy recuperation installation" itself.

For the CEA, the key point in making weapons-grade plutonium was to obtain as much Pu_{239} as possible with as few "poisonous" isotopes of plutonium as possible. The Pu_{239} produced when a U_{238} atom absorbed a neutron was not a stable isotope: with time, it absorbed more neutrons and changed into Pu_{240} and Pu_{241}. A bomb containing too large a proportion of these isotopes might "fizzle" or detonate unpredictably. The CEA team working on Marcoule's plutonium extraction factory had already settled on a chemically based process to separate the plutonium from the spent uranium fuel—a process that did not distinguish among different isotopes of plutonium. The G2 teams had little knowledge and

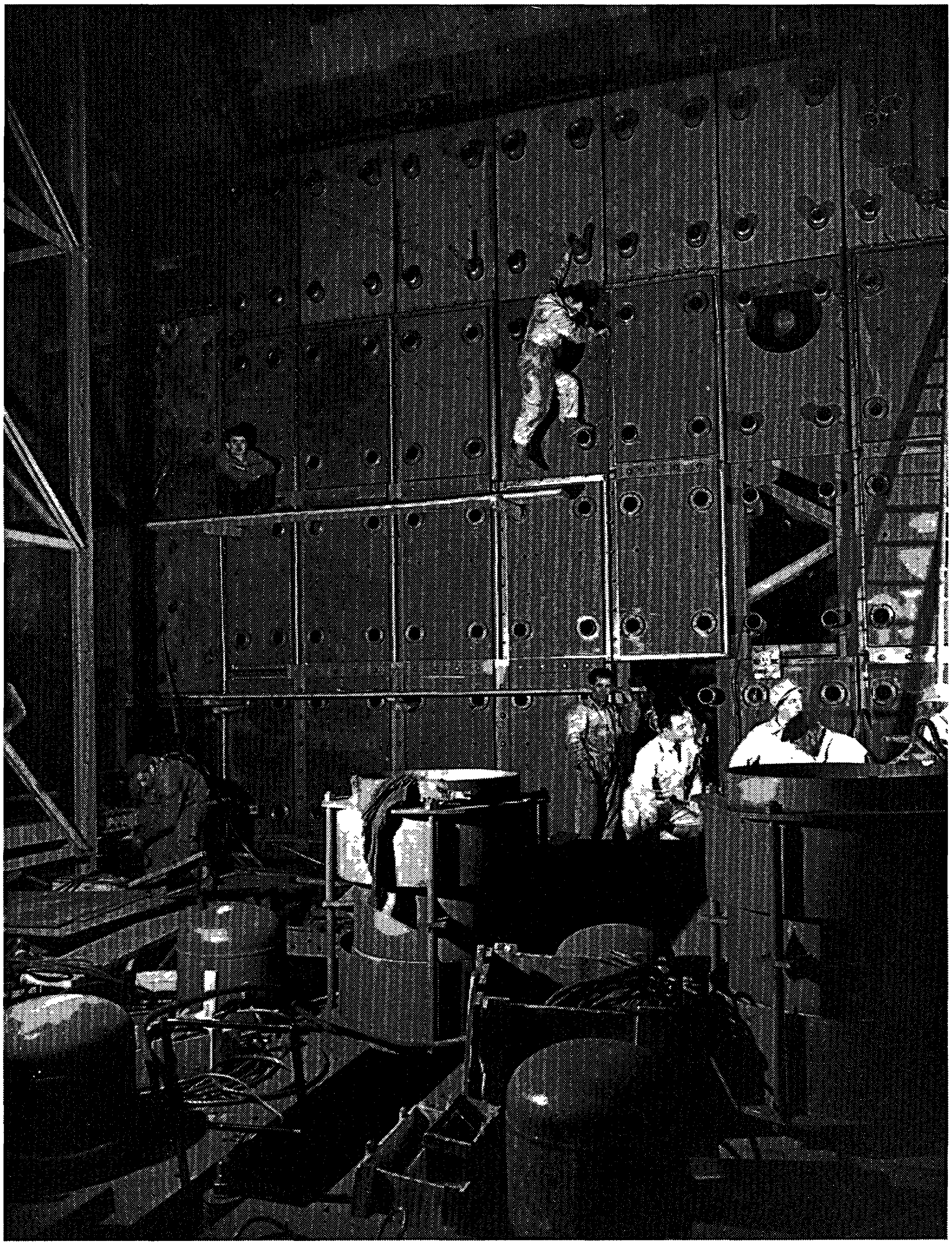

Figure 2.4
The graphite block of G2 under construction in 1957. The men climbing on the block's face are construction workers from private industry; the men in bright white suits are probably CEA engineers supervising the construction. This photograph captures the "artisanal" nature of early reactor construction. Source: CEA/MAH/Jahan.

a severe time constraint to work with; under these conditions, the only solution they could devise that would minimize the "poison" involved removing the fuel rods before too much Pu_{240} or Pu_{241} appeared. The shorter the time that each fuel rod was irradiated (that is, allowed to undergo fission), the less "poison" was produced. CEA engineers calculated that, at the optimal irradiation for producing the right balance of isotopes, any given fuel rod should not stay in the reactor longer than 250 days.[44] Had G2 been designed to produce electricity, this short irradiation period would have represented an extremely inefficient use of fuel, since it involved removing the rods before they had yielded maximum heat.

These considerations led CEA engineers to impose a technopolitical constraint on the SACM, the company in charge of designing and building this system. With 28 fuel rods in each of 1200 channels, stopping the reactor, then unloading and reloading the core channel by channel, and restarting the reactor every 250 days would have wasted far too much time.[45] And saving time was crucial to the CEA, both technologically (to avoid getting "poisonous" isotopes of plutonium) and politically (since they wanted the maximum amount of weapons-grade plutonium as quickly as possible). CEA engineers hence asked for a loading system that could function while the reactor was operating.[46]

SACM engineers chose a costly solution that fulfilled the CEA requirements perfectly (figure 2.5). A cement block containing tubular holes was built flush against the northern face of the cylindrical vessel. This block contained one tube for each channel. On the far left side, the tube connected with the loading device, which traveled on a crane built on a platform adjacent to this block. The device itself consisted of two lock chambers side by side. By maneuvering the crane up and down and from side to side along the cement block, an operator sitting on top of the crane could couple these lock chambers with any of the channels of the core. Because the operation took place while the reactor was on line, these chambers were constantly exposed to radioactivity. They were therefore encased in 56 tons of metal and concrete.[47]

The lock chamber linked up to a storage chamber containing the new fuel rods. New fuel rods would be loaded onto an elevator and brought up to the storage chamber. The lock chamber, moving back and forth on a track, would pick up the rods and bring them over to the channel; a mechanical arm would then reach into the tube and undo the plug. The new rods would be loaded into the channel, pushing the irradiated rods out. Because this entire procedure took place while the reactor was under pressure, a complex system of locks and sensors was used to create a

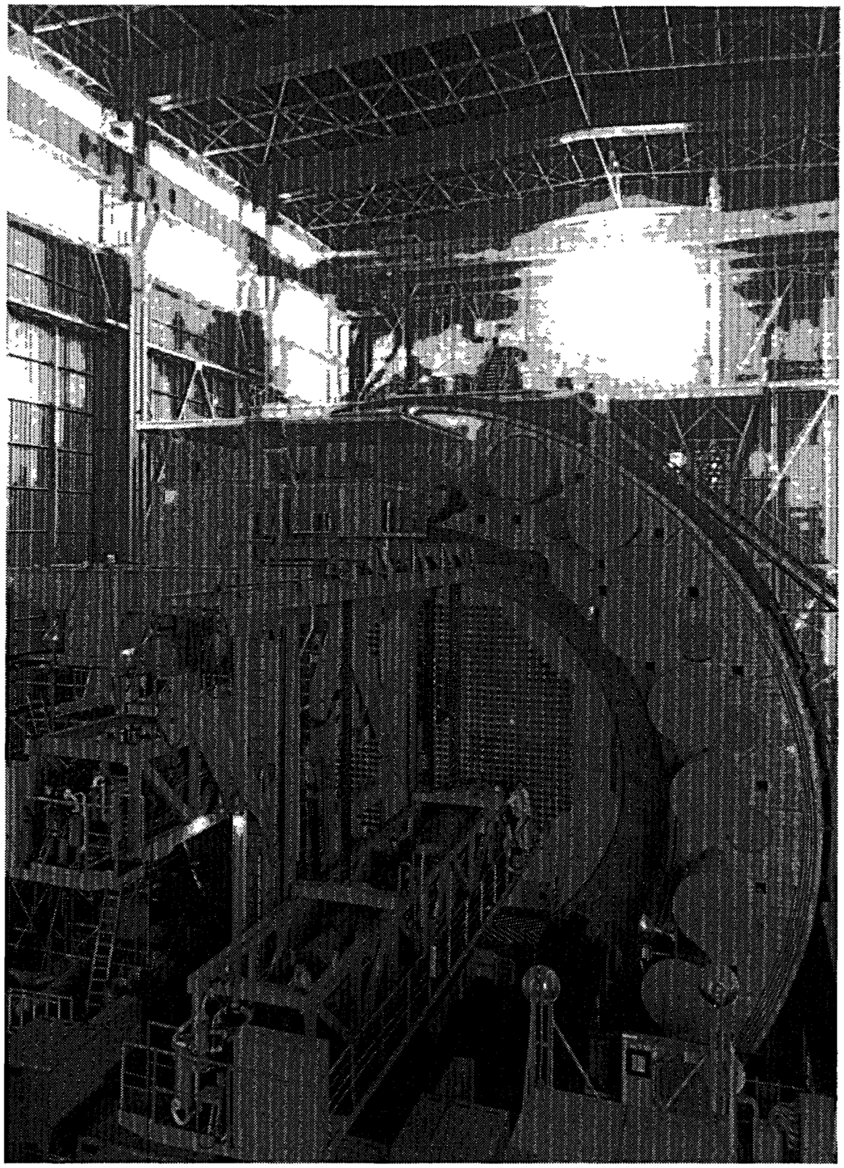

Figure 2.5
The loading machine for the G2 reactor sat flush alongside the reactor core. It gained access to the core through the canals' ends, arranged in a hexagon at one end of the core. The operator sat in the glass-encased booth at the top of the machine. Source: CEA/MAH/Jahan.

perfectly hermetic seal every time the device coupled with the storage chamber or a channel.[48]

Once pushed out the back face of the reactor, the irradiated rods would fall down a chute. They would travel onto a toboggan which dropped them into the disactivation pool, where they would cool down for several weeks before being removed and sent to the plutonium factory for decladding and processing. This system, considerably more expeditious than the one EDF would use for removing its rods, also manifested the CEA's eagerness to obtain plutonium rapidly.[49]

Fuel loading and handling was by no means the only aspect of G2's design shaped by its plutonium production goal. Another example can be found in the CO_2 cooling circuit and in the "energy recuperation installation." The "installation" contained four heat exchangers, one turbo-generator, and auxiliary equipment. The hot CO_2 gas exited the reactor core into the heat exchangers, where it cooled by transferring its heat to water. In the process, the water turned into steam. After passing through a series of pressure stages, the steam would arrive in the turbo-generator, where its heat would be converted into electricity.

Had the main purpose of the reactor been electricity production, EDF engineers would have calculated the pressure, temperature, and flow of CO_2 that would have yielded the most efficient energy retrieval. G2's plutonium priority, however, imposed severe constraints on this energy recuperation cycle. First, the reactor had to operate continuously to avoid thermal shock to the fuel rods. Second, because they had little interest in energy efficiency, CEA engineers had not designed the aluminum cladding surrounding the fuel rods to withstand high temperatures. These two constraints led the CEA to determine specific values for the pressure and temperature of the CO_2—values that did not correspond to those for optimal electricity production.[50] A third, more significant constraint was that the CEA wanted to operate the reactor at maximum power all the time. Maximum power meant U_{238} would be converted into Pu_{239} more quickly. Combined with the rapid unloading of the fuel rods, this meant that a maximum quantity of Pu_{239} could appear and be removed before too much of it decayed into poisonous isotopes. Running the reactor continuously at maximum power, however, could not be handled by the electrical network to which the heat generator was hooked up; because of variations in energy consumption, the network could not always absorb all that energy. So all these constraints forced EDF engineers to add a "desuperheater" to the circuit, placed just before the steam generator, to absorb excess heat. Furthermore, the fourth heat exchanger existed only as a safeguard in case of breakdown; in fact, three exchangers would have sufficed to run the reactor and the plant. Finally, so that the reactor could be run at maximum power and low temperature, the CO_2 had to flow through the core at a very high rate. This did not favor energy efficiency: the high rate required more electricity to power the blower, and the exiting CO_2 was at a lower temperature and therefore contained less energy.[51]

CEA engineers thus translated Guillaumat's enthusiasm for a French atomic bomb into a reactor design whose ideal function was producing weapons-grade plutonium. That G2 was something beyond a prototype for an electricity generating reactor became even clearer in 1955, when Guillaumat negotiated a secret agreement in which the Ministry of Defense agreed to finance its twin, G3.[52] While the French government waffled over whether to build a bomb, Guillaumat and his engineers took the crucial first step toward that bomb. They had almost finished building G2 in April 1958, when Prime Minister Félix Gaillard signed the order to have a bomb ready in early 1960. Without these Marcoule reactors, France could have never exploded its first bomb so quickly.

To the engineers and technicians at Marcoule, the military aspect of their work was no secret. A sense of excitement and urgency pervaded the offices in which engineers struggled over design problems and the construction sites where the huge reactors took shape. They were creating a brand new technology, and one that was of singular importance to their nation. Although they had indirect knowledge of some nuclear work that had been done in America, Britain, and Canada, they apparently did not have access to many of the technical solutions worked out by researchers in those countries.[53] They thus relied on their limited experience with experimental reactors and their ingenuity. Sometimes they favored solutions because they had heard that the British were working on something similar. More often, they favored ideas that appeared to provide the quickest, if not always the most elegant, route to completion. Frequently they had no idea whether a device would work until it had been built and attached to the reactor. The uncertainty that thus dominated their work created what many later referred to as a "pioneering atmosphere" on the job. The excitement of this atmosphere saw engineers through the 60- or 70-hour work weeks that prevailed throughout construction. One engineer has said that on February 13, 1960, after the first French atomic bomb—loaded with plutonium produced at Marcoule—exploded, he and his colleagues had been so proud of their country and the part that they had played in this achievement that they had "shed tears of joy."[54]

Much as this internal sense of pride mattered for the CEA's success, it seemed even more important to ensure that the rest of the nation's science and engineering community saw the Marcoule reactors as the epitome of French technical prowess, even if their military dimensions had to remain hidden. A few relatively minor delays in G2's construction had led to rumors that Marcoule might not live up to expectations and to complaints about the size of the CEA's budget. The CEA's public relations officer urged division heads to counteract these rumors. Guillaumat concurred, saying that "engineers who read a technical journal [had] to keep a good opinion of what we do at Marcoule" and that "for this reason, it [was] very important that stories about Marcoule multiply throughout all the branches of the technical press."[55] Accordingly, Marcoule's site director held a press conference to extol the virtues of his reactors.[56] Similarly, CEA division heads published in most of the major science and engineering journals articles that characterized Marcoule as a uniquely French achievement, piloted by the CEA and heroically implemented by French industry.[57] Francis Perrin wrote:

> [The CEA] deemed it necessary to associate French industry with these great achievements which prepare the way for the development of the industrial use of nuclear energy. French industry answered this appeal, despite deadline and supply constraints that were often severe. . . . Above all, the result of this collaboration is apparent through the two massive buildings that dominate, by their 50 meters, the banks of the Rhône. [They are] a modern replica of the ancient wall of Orange that faces them. . . .[58]

Marcoule was not only French by birth; it was also French by association and heritage. According to the site's director, "the Arc de Triomphe of the Etoile would easily fit in the vast metallic structure that shelters . . . G2."[59] The prestige that Marcoule derived from being associated with historical monuments was transitive: as a great and uniquely French achievement, Marcoule in turn would embody and strengthen French greatness. Thus the CEA's technopolitical regime sought to propagate its ideology throughout French industrial and engineering circles.

Such articles also aimed to present the Marcoule reactors as producers of reactor fuel and prototypes for power plants. That G2 did in fact generate a modicum of electricity (25 megawatts under the best of circumstances) enabled engineers and managers to describe it as a successful prototype worthy of the tremendous investments made in the nuclear program. A 1957 article in a French civil engineering journal said:

> The first stage of the plan called for the construction of two nuclear reactors (G1 and G2) that were supposed only to produce plutonium *destined to fuel the secondary reactors of the future*. . . . But during the study, we were led to envisage using the heat released by these reactors to produce electric energy. . . .
>
> Currently, the predicted total investment amounts to 60 billion francs. *This financial effort is justified by the necessity to develop, on the industrial scale, the production of electrical energy of nuclear origin*, due to the insufficiency of European resources in fossil fuel. The role of Marcoule is essentially to allow this development, to train teams of operators at different levels, and to promote technical and industrial progress in this field.

> Investments should thus not be measured against the power of the installations, but against the development potential that they bring. In fact, the [amount of these investments] is quite in proportion to the increase in our energy needs. . . .[60]

The CEA thus actively sought to control the political meanings of its reactors. The ambiguity of its gas-graphite design enabled engineers to do so easily. Unable until 1958 to promote Marcoule as a linchpin of French military security, they portrayed G2 and G3 as power plant prototypes, sources of precious fuel (and therefore independence), and exemplars of French engineering prowess. These representations, in turn, enhanced the technopolitical flexibility of the reactors' design.

This flexibility made G2 a powerful strategic tool for the CEA's technopolitical regime. We can see a striking example by briefly examining the first ministerial-level discussions on the French bomb. These occurred in late 1954 in a series of meetings presided over by Pierre Mendès-France, then prime minister. Those present included Pierre Guillaumat and Francis Perrin of the CEA, the Minister of Finance, the Minister of National Defense, the Secretary of State for Research, and various ministerial cabinet members. Guillaumat, the Minister of National Defense, and others in favor of building a French bomb tried to push Mendès-France into making an official decision to that effect, arguing among other things that a bomb effort would have advantageous fallout for the civilian sector.[61] Mendès-France later recalled the meeting this way:

> I remember asking which part of the research under way was of economic interest, and which was only of military interest. They retired to a corner of my office to discuss matters in a low voice, and several moments later, they came back and told me, "for another three years, we won't be able to distinguish the military from the civilian; only after three years will we reach a branching point when we can say: this is purely military, and that holds a purely economic interest." Under those conditions, I said, there's no problem: we must continue to do research. . . . There was no question of amputating the positive aspects of such research work from the French economy.[62]

Thus Mendès-France chose not to decide.[63] His government lasted only two more months, so he never reached that fateful "branching point." His response, meanwhile, enabled Guillaumat to continue pursuing his military agenda. The CEA Administrator General later recalled: ". . . each one interpreted [the meeting] the way he wanted to. . . . Without lying too much, [I] understood that Mendès had given us the go-ahead."[64] Successive ministers also flirted with making a firm decision, repeatedly falling back on the versatility of the Marcoule design as a means of avoiding a potentially unpopular choice.[65]

Meanwhile, scientists within the CEA who opposed the idea of a French bomb also attempted to capitalize on the versatility of the gas-graphite design. Eager to experiment with other types of reactor design, they wanted to use Marcoule's plutonium in breeder reactors (and in other types). Their proposals for the CEA's future included scenarios in which Marcoule's plutonium would go straight into secondary reactors—first to augment impoverished uranium fuel, then as the main fuel for breeder reactors.[66]

Attempts to co-opt Marcoule's plutonium proved fruitless, however, and by 1956 most scientists appeared resigned to—though in some cases resentful of—the CEA's military mission. Guillaumat later recalled: "Perrin always resented, kind of legitimately, the artisans of this first atomic plan for having suddenly produced a mass of plutonium that really only had one use. Sure, the possibility existed of making plutonium-fueled reactors, but that was extremely chancy."[67] Some proposals for experimenting with other types of reactor design did go through, but it was clear that Marcoule's plutonium would fuel bombs for the foreseeable future.[68] Indeed, the CEA had begun to pursue other aspects of weapons technology, through covert agreements with the military.[69] Technopolitical versatility was an important strategy in all these efforts. Publicly, for example, the creation of a military division within the CEA in 1956 was aimed at building a nuclear submarine; in addition to a submarine, however, researchers in that division also investigated aspects of bomb design. That year the CEA's steering committee also began seeking approval to build a uranium enrichment plant.[70] Ostensibly, this plant would enrich uranium to fuel future secondary reactors—indeed, several scientists wanted the plant for precisely this purpose.[71] The plant designs under consideration, however, all included technologies that would enrich uranium to weapons-grade concentrations, and the final plant design was clearly geared to this end.[72]

Thus, by April 1958, when Gaillard signed the bomb order, a complex technopolitical regime governed the CEA. Gas-graphite reactors, industrial contracting according to a "policy of champions," and the uranium enrichment plant were more than mere outcomes of that regime's choices. They were the means through which CEA technologists expressed and enacted their commitment to a French atomic bomb, and to French technological prowess more generally. As hybrids of technology and politics, they solidified the CEA's regime and were key components in its technopolitics. Precisely because of their ambiguous and hybrid nature, G2 and G3 extended the power of the CEA's leaders beyond the confines of the institution into the national political arena. Their ambiguity—and their power—derived simultaneously from the versatility of their design and the ways in which CEA administrators and engineers capitalized on that versatility. Depending on the audience and the political climate, the Marcoule reactors could be presented as purely civilian, purely military, or somewhere in between. This flexibility ensured their continued development; it also enabled the de facto pursuit of a nationalist military nuclear policy well before the government was willing to commit to any such thing.

EDF: The Emergence of a Nationalized Regime

Unlike the CEA, which had emerged from backstage negotiations, Electricité de France was formed after protracted debate among the multitude of political parties that vied for power after World War II. The main technical idea behind EDF—to unify the production, transmission, and distribution of electricity in a single, enormous utility—was not new. Before the war, several members of the Corps des Ponts et Chaussées had begun to design such a system, trying to make sense of the plethora of smaller networks that ran on different frequencies and voltages and attempting to merge some of the nation's private utilities. But political backing for this plan did not exist until after the war. Only then was there a widespread consensus that these private utilities epitomized the problem with French industry: they were represented as "Malthusian" companies that shunned innovation and privileged short-term profit making over reliable public service. State engineers, labor unions, and politicians of most stripes agreed that the new France should be on a single, standardized electrical network run by a single, public utility.

Even so, nationalization meant different things to different groups. On the left, some saw it as the first step toward a socialist system, while others viewed it as a simple improvement of conditions within the capitalist system. Centrist parties saw nationalization as merely a practical step toward economic modernization, with no ulterior political meanings or implications. The right denounced it as the first step toward totalitarian statism. Debates ensued on the autonomy of the new utility, the source of its capital, the hierarchical structure of management in the company, and the labor contract for its workers. In April 1946, a nationalization law was passed that regrouped the private companies into a single electric utility, EDF, accountable for its expenditures to the Ministry of Finance and for its development program to the Ministry of Industry.[73] The men appointed to the upper echelons of EDF management included numerous *polytechniciens,* especially members of the Corps des Ponts et Chaussées. Like the state engineers who dominated the CEA, these men brought a strong ideology of public service to EDF.

The left-wing coalition (which included the major labor unions) had the strongest voice in structuring the new utility and in defining its symbolic meaning. The left viewed EDF as the model and prescription for a redefinition of the relationship between the French worker and the French state. The utility's labor contract embodied this model by guaranteeing paid leave, making pay scales public, and incorporating representatives of labor unions in the company's managerial structure (albeit in a subordinate position).[74] The Confédération Générale du Travail (the communist labor union) dominated EDF (and has continued to do so ever since). At a time when labor strife permeated French industry, this contract, therefore, had tremendous symbolic value.[75] Pierre Simon, the utility's first president, articulated the meaning of worker participation as follows:

> In contrast to the spirit of routine, we must have a revolutionary spirit. Without a doubt, the workers can be very intelligent and can even escape their roles to become governmental ministers. Until now, there was a widespread tendency toward a separation between the roles of workers, who were to perform mechanical tasks, and managers, whose role was to define the methods of work. Today, that distinction is being suppressed. Under the old system, those who performed direct work were excluded from its conceptualization; today, we seek to associate the workers in that conceptualization.[76]

In other words, EDF promoted the active and valued participation of workers in the reconstruction and modernization of the nation. As such, it functioned as a potent public symbol of a new social order.[77]

Nationalization certainly represented a victory for the left, but it did not signal a unanimous consensus on the structure and role of the public utility. The onset of the Cold War in 1947 provided an occasion for attacks on communist strongholds, including EDF. Although these attacks weakened the formal power of the communist labor union, they did not succeed in purging communists from EDF. Unlike the CEA, EDF remained a bastion of the left. Attacks on the utility's managerial and financial practices did, however, mean that issues such as the rate structure, the choice between hydroelectric and coal power plants,[78] and the relations with private industry continued to be points of conflict within EDF and also among EDF, the government, and capitalist companies. The struggle over the meaning of nationalization for EDF would thus continue long after the utility's creation.[79]

Still, even diverging factions within EDF could agree on a few basic issues. First and foremost among these was EDF's mission: namely, to make France energy independent by producing and distributing the most electricity at the least cost. More generally, everyone agreed that the amount of electricity generated and consumed by a nation directly reflected its modernity (as did the level of ownership of electrical appliances).[80] By extension, the network for distributing electricity united and defined France symbolically as well as technologically: complete electrification would enable all French citizens to participate in the modernization of their nation. Though the implementation of worker participation provoked some disagreement, it would have been impolitic for anyone to deny its value in principle. Nationalization thus made room for everyone at EDF to embrace an ethos of public service. Working for EDF meant apprehending and serving the entire nation through the production and distribution of electricity.

These basic ideological principles underlay EDF's efforts to establish its own technopolitical regime within the nuclear program. The utility's interest in nuclear power began in the early 1950s with Pierre Ailleret, the director of its research division. Ailleret, also a member of the CEA's steering committee, had persuaded the CEA to add small power generating units to the Marcoule reactors. He simultaneously sought to drum up enthusiasm for nuclear power within the utility. Gas-graphite reactors had the potential to fit well within EDF's ideological scheme: designed and manufactured in France, they could provide an additional path to energy independence. Not all of EDF's top administrators shared Ailleret's burning enthusiasm for the technology itself, but the opportunity was too good to pass up. EDF had neither the time, nor the money, nor the expertise to launch an independent nuclear program—but it could collaborate with the CEA. Beginning in 1954, EDF's Director General Roger Gaspard signed a series of protocols with Guillaumat that specified the distribution of technical and financial responsibilities not only for the Marcoule reactors but also for the utility's first plant at Chinon. Financially, the CEA would be responsible for Marcoule and EDF for Chinon. Technologically, the two institutions would work together to develop EDF's reactor, whose main purpose would be to produce electricity (not plutonium).[81] The two institutions would draft development plans together and take them to the Commission Consultative pour la Production d'Electricité d'Origine Nucléaire (known informally as PEON), which had been formed in April 1955 to advise the government on matters of nuclear power development. PEON was composed primarily of high-level engineers and managers from the CEA and EDF; thus, provided the two institutions could agree on plans beforehand, commission approval would be little more than a formality.[82] And indeed the first gas-graphite development plan went through easily enough. EDF's first reactor would be a 60-megawatt plant. A succession of increasingly powerful reactors would follow, which by 1965 would total 800 megawatts.

This apparently amiable arrangement soon gave way to a series of conflicts between technologists at the two institutions. During the course of these conflicts, EDF engineers and managers established a nationalized technopolitical regime, through which they sought to prescribe and enact their own vision of France's industrial policy and their own ideas about how gas-graphite reactors should look. In order to understand the technopolitical regime that EDF upheld within the nuclear program, let us now turn to its first reactor project: EDF1.

The EDF1 Reactor: Developing a Nationalized Technopolitical Regime

The two regimes needed each other, both technologically and politically. Despite the fact that the Marcoule reactors did not produce energy in an optimal fashion, they did at least have an electricity generation unit. EDF engineers were learning valuable lessons by working on G2 and G3 (and also by taking CEA courses in nuclear engineering).[83] Politically, EDF's participation in Marcoule had buttressed the CEA's claims that the reactors there were prototypes for power reactors. Conversely, Marcoule's success strengthened the case for building separate EDF reactors. In many ways, the partnership seemed ideal.

In the course of working out the collaboration, however, each regime was also eager to establish its role in defining the future of the nuclear program and of French industrial development more generally. In theory, the terms of cooperation for EDF1 were clear: CEA teams would design the "nuclear" parts of the reactor (the core and the fuel rods). EDF teams would design the "classical" parts (electricity generation). Ultimately, EDF headed the project, and thus it would make the final decisions. In practice, though, the EDF1 project was fraught with tension between engineers in the two institutions. This tension centered around two issues: the role of private industry in the project, and the actual design of the reactor. Conflicts did not emerge because the CEA didn't want to build an electricity-producing reactor. Part of the CEA's mission was to develop nuclear technology in any form. But the distinct design and contracting practices developed at Marcoule had become integral to the

CEA's regime, and its engineers wanted EDF to follow the same practices. Notably, they wanted to preserve the dual nature of gas-graphite reactors: just as EDF had gotten some electricity out of Marcoule, CEA engineers hoped to get some plutonium out of EDF reactors. They had come to regard this versatility as an integral technopolitical part of gas-graphite design: on a technical level, gas-graphite reactors inevitably produced at least some plutonium, and this might as well be put to a good political purpose.[84] And engineers in each institution jealously guarded their expertise: CEA engineers held that their intimacy with nuclear matters gave them the edge, while EDF engineers maintained that their experience with conventional power plants gave them the upper hand.[85]

More was at stake than EDF1 alone. It was still far from clear that the nuclear program would receive long-term support. Precisely what would receive support (a military program, a civilian program, or both), and to what extent, was also uncertain, particularly before 1958. Furthermore, project participants expected that the set of working methods and expertise that prevailed in the EDF1 project would dominate, or at least influence, future reactor projects. They therefore felt that they were conceiving not one but a whole series of French nuclear reactors.[86] An examination of these conflicts will demonstrate how EDF engineers developed their own technopolitical regime by inscribing their political, economic, and technological agendas into the project and by making EDF1 into their own instrument of technopolitics.

Tensions between the two institutions first became manifest in the organization of the project. As with G2, Guillaumat and Taranger wanted private industry to coordinate the design and construction of EDF1. But EDF's nuclear team wanted to follow the contracting practices the utility had used for its conventional power plants. They held that EDF should fill the dual role of project coordinator[87] and general contractor—the dual function that the SACM had fulfilled for G2. Team members espoused the anti-capitalist sentiment that had spawned nationalization. By building EDF1, they were providing a public service. The best way to do this was to optimize the cost and efficiency of the reactor.[88] Ailleret argued that EDF, not private industry, should conduct the optimization studies "in order to be sure that we are not influenced by the industrialist's tendency to develop certain types of materials rather than others."[89] Another team leader commented disparagingly that Guillaumat and Taranger were "oil men" who "dreamed only of private industry."[90] Furthermore, the team argued, EDF should coordinate the overall design and building as well. The best way to keep costs down was to divide the reactor into parts and request bids for each part. EDF would thus retain greater control over both the knowledge needed to build the reactor and the cost of the project. To top it all off, this method of working was "politically correct": in the ironic words of a high-level EDF manager, "the pure and white EDF, a nationalized company, would acquire the know-how while leaving the builders, the capitalist companies, with the banal task of supplier."[91] In EDF's technopolitical regime, the utility would direct the development of nuclear power in the best interests of the state, with private industry merely following orders.

Overriding a furious Taranger (who maintained that the CEA's method was better for the overall industrial health of the nation), the EDF team proceeded according to its intial plan.[92] The first step now was to draft preliminary blueprints. Jean-Pierre Roux, the head of EDF's design team, had asked the CEA to do so in July 1955. But his team found this proposal, heavily based on G2's design, unacceptable: the team intended to generate electricity "optimally," something G2 did not do.[93]

The EDF team sought to change practically everything in the CEA's proposal.[94] In order to optimize the reactor for electricity generation, they wanted to control the definition of almost all the components and parameters, including components such as the uranium-graphite pile and the devices for loading and unloading the fuel, as well as parameters such as the pressure of the CO_2 cooling gas and the operating power of the reactor.[95]

The finished design of EDF1 (figure 2.6) looked quite different from that of G2. The most noticeable and perhaps the most symbolic modification was the location of the heat exchangers: right next to the pressure vessel that contained the core (rather than many meters of energy-losing pipes away), and inside the reactor building (rather than outside). The reactor still ran on natural uranium, encased in fuel rods similar to those of G2, and it was still moderated by graphite and cooled by CO_2. Just about everything else, however, had been changed.

The EDF team insisted on changing the operating pressure of the reactor and the pressure vessel containing the core. The CEA team had suggested a prestressed concrete vessel like the one at Marcoule. It argued that, in addition to being a tested technique, prestressed concrete was a domain in which France had outdistanced other nations. Adhering to the "policy of champions," CEA officials felt a responsibility to encourage French industry to reinforce its areas of excellence.[96] But EDF engineers found this vessel too expensive. They feared that prestressed concrete could not withstand the temperatures at which they planned to operate

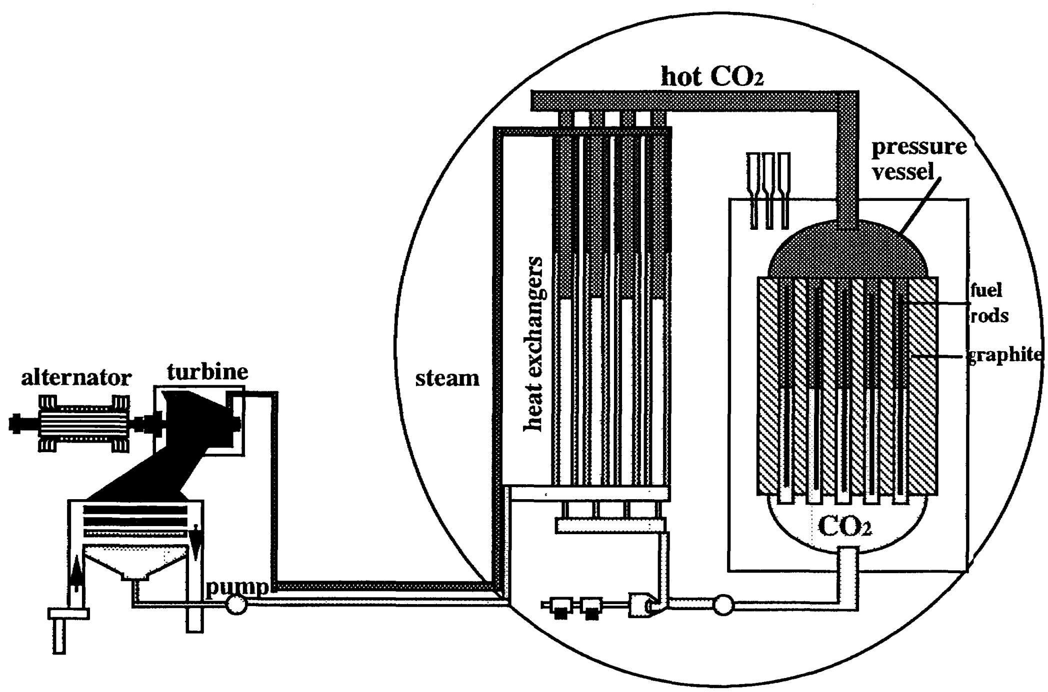

Figure 2.6
A schematic diagram of EDF1 (not to scale). Source: EDF, Rapport de sûreté Chinon A1, 1980. Drawing by Jay Slagle.

the reactor, and that it would require its own special cooling circuit. This would increase overall operating costs and lower the reactor's energetic efficiency: the blowers needed to pump the CO_2 through the special circuit would use up 10 percent of the electricity generated by the reactor.[97] Instead, EDF engineers chose a steel vessel, cylindrical in shape, capped by a steel hemisphere on either end.[98] Steel could withstand higher temperatures and pressures. In addition, the fact that the United States and Britain had built steel reactor vessels gave the French engineers confidence that they too could build a working steel vessel. For them, national pride would derive from the production of cheap, reliable electricity, not from promoting minor, if uniquely French, technologies.[99]

Early on, EDF engineers decided that EDF1 should function at a higher pressure than G2: 25 bars instead of 15. Lower-pressure reactors were easier and faster to build, and speed had mattered politically to CEA technologists in the G2 project. But a lower operating pressure meant that a higher flow of CO_2 was needed to extract the heat, which required more powerful blowers, thereby lowering the reactor's efficiency.[100] EDF engineers had also decided that the loading and unloading of the fuel would take place while the reactor was stopped. Unlike the CEA, EDF wanted to burn up the fuel rods as much as possible in order to extract the maximum amount of heat. In 1955, engineers designing EDF1 could imagine little use for a device that could move rods in and out of the reactor very quickly. They hoped that a loading device that could only work off line would limit how much weapons-grade plutonium the CEA could demand from EDF1.[101]

Having decided on this loading principle, the EDF team then decided to orient the channels containing the rods vertically, rather than horizontally as in G2. In a vertical configuration, the CO_2 could be pumped in at the bottom. It would thus follow the natural convection of heat, growing hotter as it rose. This meant that less pumping power was required for the CO_2, and it made the overall design safer in case of blower failure. A vertical pile also required fewer openings in the pressure vessel, thereby making it easier to ensure that the core was hermetically sealed. It also meant that the reactor could be loaded and unloaded from the bottom. Bottom loading involved using "a single loading arm capable of reaching all the channels and requiring only one opening in the shell, although clearly a large one."[102] EDF engineers found this system simpler and cheaper than the G2 design,[103] which had separate openings in the vessel for each channel and a huge machine designed to have access to every channel.

EDF engineers thus advocated a design that they felt would make most efficient use of both fuel rods and investments and that would be as simple as possible so as to provide a good basis for future reactors.[104] Both through the design itself and through the industrial contracting process, EDF engineers sought to redefine what a reactor was, how it should be built, and what it should be used for. By modifying pressure and temperature, EDF engineers had designed a reactor whose performance and capabilities matched their regime. They hoped that in future collaborations the CEA would have to work with these new parameters.

EDF engineers found that the process of designing a power reactor involved a great deal of guesswork and intuition. In the mid 1950s, they had no more access to foreign technology than did their CEA colleagues. They therefore chose technical solutions that they thought would further their political, economic, or industrial goals. Sometimes they simply favored options that would differentiate their regime from the CEA's. By the mid 1960s, when they began designing EDF4, they had revisited several such solutions and had found ways to make prestressed concrete vessels and continuous fuel loading suit their purposes. What mattered in the mid 1950s, though, was that technologists within the utility (and in

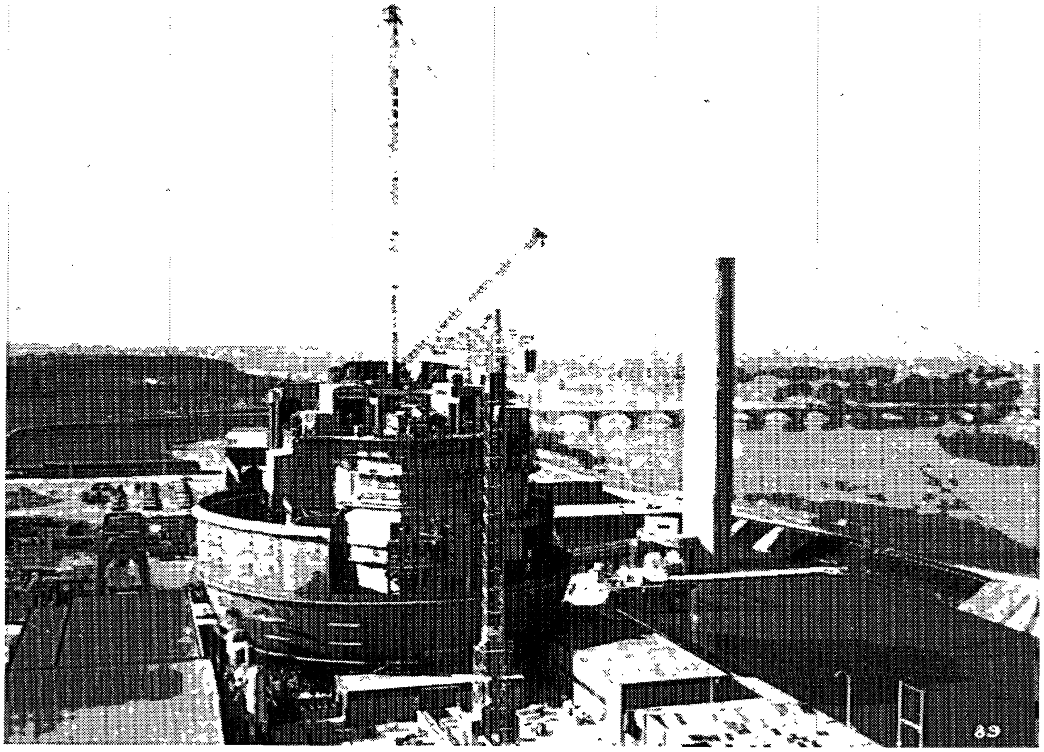

Figure 2.7
EDF1 under construction in 1962. Photograph by H. Baranger. Source: EDF Photothèque.

the relevant ministries) believed that EDF1 engineers had designed the project that best suited the utility's regime.

How the EDF engineers viewed their work is evident from the way they promoted their achievements to other French engineers—inside as well as outside their institution, for not everyone at EDF believed that nuclear energy would ever compete with conventional power plants.[105] Some of their prose paralleled that of CEA engineers, explaining that "anguishing" shortages in energy resources justified the huge "financial sacrifices" made for the nuclear program—sacrifices that, in any event, would soon pay off, since nuclear energy increasingly seemed like a "providential solution."[106] At the same time, their rhetoric frequently sought to differentiate their regime. For example, one engineer contemplated the day when EDF would no longer have to use natural uranium—a choice in which it had played no part, although its engineers had accepted the choice without complaint: "The inferiority of natural uranium piles is less economic than it is energetic. Later, when we move to another kind of reactor that allows us to use enriched fuel, it will be less to lower the cost of the kilowatt-hour than to reduce the specific consumption of fuel and increase, in considerable proportions, the amount of energy that can be drawn from natural reserves."[107]

Certainly EDF engineers had reason to be preoccupied with the overall "efficiency"—both energetic and economic—of their electricity-generating technologies. In order to get France's energy sector back on its feet, EDF had built as many conventional power plants as it could, as quickly as possible, in the first ten years after the war. The resulting hydroelectric program had paid less attention to cost than to speed and reliability. In the face of sharp criticism in the early to mid 1950s, EDF had adopted an institution-wide policy of *rentabilité* (best translated here as economic viability), which coincided with the priorities of the second plan elaborated by the nationwide Planning Commission.[108] Engineers hence had to show that their designs would not lose money and would make efficient use of fuel. Already, the engineers who had built the hydroelectric plants were fighting with those in charge of coal-fired thermal plants over whose work best fulfilled these requirements.[109] EDF's nuclear team therefore aimed its arguments about the benefits of nuclear energy at the world outside its regime, whether that be within the utility or beyond it.

Utility engineers compared their achievements with those of other nations, especially Britain. Jean-Pierre Roux compared EDF1 with the Calder Hall reactor and concluded "that this French project holds up under comparison with the English projects."[110] Especially, he continued, when one considered that the British took five to six years between reactors, whereas the French were only taking two. Waxing eloquent on the benefits of nuclear energy, other engineers emphasized that building nuclear reactors fulfilled their mission of public service to the French state and the French people:

> The path taken in giant steps during the past few years in the four large atomic countries, and especially in France, allows the highest hopes.
>
> It is not chimerical to think that the moment of massive realizations approaches rapidly.
>
> Placed at the disposal of all, in the workshop and in the home, nuclear energy will allow economic and social progress to continue everywhere in the world, and in the European community in particular.
>
> France must reap the moral and material benefits that she has the right to expect from a technology so often fertilized by her scientists and already so widely developed by her engineers.[111]

Just as CEA engineers had sought to shape the meanings of Marcoule to enhance its technological and political versatility, EDF engineers sought to demonstrate how Chinon upheld—indeed constituted—the utility's technopolitical regime within the nuclear program. Like the utility itself, nuclear energy would promote "social progress." It would promote democratic values by being "at the disposal of all." Under EDF's guidance, France's development of nuclear power would proceed rapidly and efficiently, easily competing with Britain's and thereby bringing the nation the "moral and material benefits" that were its due. EDF took just as much pride in French achievements as did the CEA, but it located the source of pride in the practices of a nationalized institution.

*

Both G2 and EDF1 were hybrids of technology and politics. There existed no single best way to build these reactors; they were not the inevitable products of some progressive logic inherent in the technology. Nor were they the infinitely malleable products of political negotiation. Rather, each reactor resulted from a seamless blend of political and technological goals and practices.

For both regimes, building these reactors entailed the pursuit of technopolitics. French military nuclear policy in the 1950s was not made by government officials contemplating their nation's place in the postwar world and firmly deciding to build a bomb. The political chaos of the Fourth Republic precluded any deep consideration of nuclear policy. Heads of state, ministers, and elected officials gladly allowed state technologists to make nuclear policy. In the absence of a traditional political formulation of nuclear military policy, the Marcoule reactors *were* that policy, containing both the ambiguities and ambivalences of Fourth Republic governments and the goals of men like Pierre Guillaumat and Pierre Taranger. As a counterpoint to G2 and G3, EDF1 was also policy and politics. EDF engineers seized on the energy-producing potential of the gas-graphite design to direct nuclear policy more firmly toward energy production. They used their technological choices in the EDF1 project—and the fact that those choices differed from the CEA's—to convince others in their institution, as well as bureaucrats and ministers who might fund their program, that nuclear energy could present a viable economic alternative to conventional power sources.

Thus CEA and EDF technologists deliberately—even proudly—sought to make their technologies into instruments and embodiments of politics. CEA engineers may have obscured the full extent of their political aims for some audiences, but they never tried to hide the fact that they had political aims. Nor did their EDF counterparts. *Politics and policy making* *gave the reactor projects significance*, both within the each regimes and in the interactions each had with its surroundings. For example, EDF1 was important not because it would produce economically viable electricity, but rather because it represented the first step in a nationalized nuclear program that would enact and strengthen the utility's ideology and its industrial contracting practices. At the same time, the *technological form* of their politics gave technologists power and influence. For example, Pierre Mendès-France displaced his decision onto the shoulders of CEA leaders, whose authoritative assurances about the flexibility of their technologies enabled him to abstain from deciding about a bomb. Meanwhile, this same flexibility allowed CEA technologists to persist in their pursuit of the military atom.

CEA and EDF engineers had a common interest in promoting a nuclear program and a shared heritage of public service. Working together, they sought to establish the nuclear program as an arena in which to play out issues of great significance to the French nation and its identity. For both groups, developing a nuclear program provided a means of making France a technologically powerful nation—of recasting the symbols of French identity in technological form.

But the precise nature of that form differed. Engineers and managers in the two institutions had diverging visions of the public interest and of the nation's future. Their efforts to translate these visions into technological practices and artifacts resulted in two distinct technopolitical regimes. The CEA's nationalist technopolitical regime found form in its Marcoule reactors and in its "policy of champions." EDF's nationalized technopolitical regime found form in its Chinon reactor and in its efforts to micromanage industrial contracting. Both regimes sought to develop prescriptions for governing nuclear development within their institutions and for directing nuclear and industrial policy on the national stage. Embedding these prescriptions in artifacts and practices constituted a strategic move in which technology and politics were deliberately conflated. Thus the reactors at Marcoule and Chinon functioned as strategies through which the two regimes aimed to retain power over both the technological and the political dimensions of nuclear development.

We can understand this strategic practice of embedding policies in reactors as technopolitics—that is, politics conducted through specifically technological means. Technopolitics differ from regular politics in two important respects. First, technopolitics is conducted not by elected officials but by technologists (in the broad sense defined in chapter 1).

Second, its power derives from its grounding in expert knowledge and its expression in material artifacts or practices.

These regimes were neither uncontested nor static. Shortly after his arrival, Guillaumat dismissed several communists from the CEA under the guise of a reorganization. Employees widely interpreted this move as signifying that the CEA would engage in military activities, and a series of protest strikes ensued that lasted, on and off, for two years.[112] The strikes did not alter Guillaumat's course, but they did show that the nationalist technopolitical regime he had spawned would need to remain vigilant in order to retain control of the institution. As we have seen, a subtler form of resistance came from some of the CEA's scientific leaders, who sought to redirect gas-graphite technology toward more peaceful ends by promoting the development of breeder reactors. These efforts met with partial success, largely because the breeder promoters fitted their project proposal within the framework and prescriptions of the nationalist technopolitical regime. Although Marcoule's plutonium remained (at least in the short run) destined for weapons, the CEA also launched an experimental breeder reactor project. This project would provide important technopolitical support for that regime in the late 1960s, when the gas-graphite program would be threatened.

EDF's earliest efforts to establish a technopolitical regime in the nuclear program did not engender much opposition inside the institution. As the program grew, however, so did the stakes. The 1960s witnessed growing struggles, both inside the utility and between EDF and the CEA, over the methods and practices according to which reactors should be designed and built. In the course of these struggles, both technological and ideological components of EDF's nationalized regime underwent a series of shifts.

3

Technopolitics in the Fifth Republic

As the strategic practice of designing or using technology to constitute, embody, or enact political goals, technopolitics is a distinctive form of political action. Its effectiveness, however, depends at least partially on the broader political framework. The success of the CEA's technopolitical regime in the 1950s was due in good measure to the ministerial instability of the Fourth Republic and its leaders' collective unwillingness to engage in more conventional forms of nuclear policy making. These conditions changed in 1958, when Charles de Gaulle returned as head of government after a twelve-year absence.

De Gaulle and his allies attached tremendous symbolic importance to French nuclear achievement. The ensuing centrality of the nuclear program to government politics had double-sided and somewhat ironic results for its developers. The program acquired greater importance, but the actions of nuclear leaders underwent greater scrutiny. Gaullists fully embraced the notion of technological radiance, which gave technologists greater visibility and respect. This in turn meant that technopolitics became a more important and powerful form of political action. It also meant, however, that technopolitics became more complex and contested. Conducting nuclear technopolitics now involved more than embedding preexisting political goals into technological artifacts. Increasingly, technologists had to shape their agendas and practices in ways that would be compatible with Gaullist discourse on national identity and industrial development. The technopolitical regimes of the CEA and EDF no longer had exclusive control over the terms in which debates about France's nuclear future were conducted.

In this chapter, in order to understand these changes, I return to the debates between the CEA and EDF over the development of the gas-graphite reactor program. Here I concentrate less on final reactor design and more on design practices, project organization, and pro-