History and Technology

An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ghat20

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To cite this article: Esther M. Sánchez Sánchez (2022): The training in France of Spanish nuclear personnel, c. 1950s–1990s, History and Technology, DOI: 10.1080/07341512.2022.2076402

To link to this article: https://doi.org/10.1080/07341512.2022.2076402

HISTORY AND TECHNOLOGY
https://doi.org/10.1080/07341512.2022.2076402

The training in France of Spanish nuclear personnel, c. 1950s–1990s

Esther M. Sánchez Sánchez

Department of Economy and Economic History, Universidad de Salamanca, Spain

ABSTRACT

Foreign assistance was decisive in the formation of the teams in charge of nuclear science, technology and industry in Spain. France played a key role from the end of World War Two, assisting Spanish expertise in all stages of the uranium cycle, from mining to disposal. In this paper, after examining the configuration of the French nuclear complex and the start of French-Spanish cooperation, we will focus on the training of Spanish nuclear personnel, in both the scientific-technical and the industrial side. We will try to prove the importance of France in the whole Western nuclear assistance, and also that, though France was unable to supplant the United States, it was able to grab significant projects and influence in Spain. In the end, nuclear learning proved to be a cumulative and mutual (not symmetrical) process, which far exceeded the temporal, geographical and sectorial limits initially marked out.

KEYWORDS

France; Spain; nuclear fuel-cycle; nuclear assistance; nuclear training; Cold War

Introduction

In 1945, the great achievements of the United States in industrial and scientific-technological matters contrasted with the hardships of a shattered, demoralized, and hungry Europe. However, the gap started gradually to close thanks to American aid and Western European cooperation, which were the germ of the socioeconomic growth of the 1950s and 1960s. This climate of cooperation was fully embraced by the nuclear sector, which became one of the leading protagonists of international relations in the second half of the twentieth century, involving numerous countries, disciplines, and actors. From the early 1950s, the US provided information and nuclear technology products in exchange for controlling the nuclear facilities of its Western allies, and so ensuring that nothing was diverted to military applications.[1] The American display was an exercise in *soft power*,[2] based on persuasion rather than coercion and on what was seen as constructive rather than destructive engagement. This ensured collaboration, consensus, and knowledge co-production; that is, mutual interaction and feedback between the two sides of the Atlantic.[3] While it is true that US technology unleashed many national research efforts, European partners also adapted the American methods to their local conditions and specific needs, and even maintained divergent paths. Many recent works have revised the idea that Americanisation meant the total and uncompromising alignment of European

CONTACT Esther M. Sánchez Sánchez esther.sanchez@usal.es

societies with US cultural and political models. One must instead see Americanisation as a complex transfer process which was not a matter of direct and unidirectional adoption, but a complex of interactions involving active choices of adaptation and even rejection.[4]

France was a paradigmatic case in this regard.[5] Indeed, the US failed to dissuade France from formulating its own independent nuclear policy, designed for both civilian and military purposes. The formidable efforts made by the French at the end of World War Two were added to their long tradition in the field of radioactivity, associated with emblematic figures such as Becquerel and the Curie family.[6] From the 1950s onwards, France became an atomic power capable of autonomously providing technological and financial assistance to the Spanish nuclear program, albeit not without difficulties and always lagging behind the US.

Spain tried hard to develop a nuclear industry, similar to that of the great world powers, that would alleviate energy restrictions while providing political returns. This plan was supported by relevant personalities within Franco's regime, the views and actions of which did not always coincide. During the autarchy years (c. 1940s–1950s), the first steps were taken to acquire knowledge and skills, under the leadership of the government and the military. In the development stage (1960s–1970s), an ambitious nuclear power plant construction program was launched, in which public powers and private initiative finally converged, though not without tension. The magnitude of the projects, together with the relative technological backwardness and the low financial capacity of the Spanish economy, made foreign aid essential. But it was not enough to import capital and technology. It was also necessary to create a domestic industrial, business, and scientific-technical environment capable of internalizing learning from outside in the short to medium term. As in other latecomer countries, foreign agents were actively involved in the training of local human capital, with the help of companies and public bodies from the sending and receiving countries.[7] The result was that a peripheral country ruled by a dictatorship was able to access nuclear technology, one of the most expensive and complex technologies of the times, just a few years after the acknowledged world powers did. Spain learned abroad and bought from the Western powers the high-tech systems, but succeeded in developing its own instruments and techniques in various steps of the nuclear fuel cycle (mining, milling, conversion, fuel fabrication, electricity generation, and managing radioactive waste). Thus, as in the US and France, nuclear knowledge and technologies circulated far beyond the academic community and became vectors of diplomatic and political relations and even social cohesion, particularly when they engaged in training and information efforts.[8]

Those works that have dealt with the subject of the training of Spanish personnel in the nuclear sector from the point of view of economic history and the history of science and technology have been focused on Germany, Italy, and, above all, the US.[9] The purpose of this article is to examine the role of France, which from early dates assisted Spanish expertise in all phases of the fuel cycle, from uranium extraction to spent fuel management. In the first section, we will look briefly at the configuration of the French nuclear complex, with the purpose of stressing its oversized character (and overinvestment), and so understand its need to cross borders. Indeed, France needed access to foreign markets to get returns on the huge investments made, to test developing technologies, and to increase the exports of the many companies (big and small, state-owned and private) that had emerged in the heat of the nuclear sector. Spain was considered as an excellent option, given its historic ties to France and its ambitious (and much needed) nuclear program. France was also interested in Spanish natural uranium, especially before discovering the big reserves of its former colonies Gabon and Niger. Furthermore, Spain was seen as a springboard to boost French exports to countries geographically and/or culturally close (Portugal, and many Latin American countries), or to countries seeking to reduce the predominance of the US.[10] In the second section, we will explain the start of nuclear cooperation between Spain and France, identifying the most prominent people and organisations, and reconstructing the interactions that were set up among them. We will try to demonstrate that French and Spanish nuclear agents approached each other to diversify their economic and foreign policy options, namely reducing their heavy dependency on the US, and paving the way towards closer relations with European governments and businesses. The rest of the paper will focus on the training of Spanish personnel, in both the scientific-technical and the industrial aspects. We will make a claim for the importance of the French role in the combined foreign assistance, analysing the different phases and beneficiaries of the training processes. Finally, we will try to prove that, though France was unable to supplant the US, it was able to grab projects and influence in Spain, and that nuclear learning was a cumulative and mutual (not necessarily symmetrical) process, which far exceeded the temporal, geographical, and sectorial limits initially marked out.

France and the race for the *Tout Nucléaire*

From the start, the French nuclear program combined civil and military dimensions. In 1945, when France was still convalescing from World War Two, the provisional government of General Charles De Gaulle created the Commissariat à l'Énergie Atomique (CEA, Central Commission of Nuclear Energy), with the mission of 'promoting and coordinating nuclear research in all areas of science, industry and national defence'.[11] The following year, electricity was nationalized, after the absorption by Électricité de France (EDF) of some 1,300 companies producing and/or distributing electricity. The CEA and EDF became the main protagonists (not always well-matched) of the French nuclear adventure. Through the nuclear sector, France dealt with its scientific, industrial, and political recovery, and hence the restoration of its national pride, after the trauma of defeat and occupation.[12] From the early 1950s, the management of the French nuclear program, standardized in five-year plans, was left to an elite group of engineers (the Corps des Mines, and Corps des Ponts et Chaussées) who were granted direct dialogue with the State, access to privileged financing, and often exemption from parliamentary scrutiny (the *nucleocrats*).[13] The State also promoted the creation of large business groups, such as Indatom (1955), the Groupement Atomique Alsacienne-Atlantique (GAAA, 1959), and the Société d'Études et d'Entreprises Nucléaires (SEEN, 1965), in which several dozen *champions nationaux*, public and private, related to the nuclear industry were integrated (Alsthom, Péchiney-Ugine Kuhlman, Empain-Schneider, Compagnie Générale d'Électricité and Saint Gobain Pont-à-Mousson, among others).

The first power reactors, installed in the Marcoule complex, were dual-use units that in addition to generating civil electricity produced plutonium to create atomic bombs. This aspiration, shared by the governments of the Fourth and Fifth Republics regardless of their political colour, became a reality in 1960: with De Gaulle again in charge of the

Executive, France entered the exclusive club of countries with the atomic bomb, together with the US, Great Britain, and the Soviet Union. The first reactors dedicated to the production of electric power – those of Chinon, Chooz, and Saint-Laurent-des-Eaux – were connected to the grid in the 1950s. They used a technology of French conception, based on the combination of natural uranium as fuel, graphite as moderator, and carbonic gas as cooling fluid (UNGG reactors).[14] At the time, the international market for commercial reactors was dominated by the American firms Westinghouse (supplying the Pressurized Water Reactor [PWR]) and General Electric (Boiling Water Reactor [BWR]), which used enriched uranium and light water. UNGG technology reflected the French will to achieve greater national independence and a larger global role in the Cold War (the so-called French *Grandeur*). Uranium enrichment on an industrial scale was at that moment a technology exclusive to the US and the Soviet Union. Both sold it to their respective allies, at a low price, but in exchange for close monitoring. Consequently, France opted for natural uranium, which would be extracted and processed in French national territory (mother country and colonies). The UNGG reactors had an additional attraction: they generated a higher amount of plutonium than that of the PWR and BWR reactors, plutonium that could be used both in civil projects (fast breeder reactors) and military projects (atomic weapons), and whose control would exclusively be the responsibility of French institutions.[15]

For almost two decades, economic considerations were subordinated to political and military imperatives.[16] France built a total of 11 UNGG-type reactors, significantly more expensive than rival American reactors. In addition, the nation devoted enormous efforts to fast breeder reactors (*Rapsodie, Phénix*, and *Superphénix)*,[17] as well as atomic armament (plutonium bombs, hydrogen bombs, and means for their transport).[18] The 1960s witnessed the technological controversy (*guerre de filières*) between the UNGG and PWR procedures, a dispute that was resolved in 1969 in favour of US technology, basically for reasons of economic profitability. The company Franco-Américaine de Constructions Atomiques (Framatome), founded in 1958, acquired Westinghouse licenses for the construction of PWR reactors in France. Over time, the French adapted and 'Frenchified' them, giving rise to the European Pressurised Reactor (EPR), the European version of the PWR.[19] Despite the desire for independence, the reality was that a good part of the French nuclear procedures were linked to the American ones, acquired by various means: French scientists, engineers, and technicians trained across the Atlantic, courses organized in Paris within the framework of the 'Atoms for Peace' campaign (e.g. the 'Atomic Energy Course for Management' by General Electric), and commercial and scientific-technical exchange agreements between both countries.[20]

The oil crisis revived the desire for energy independence and led to a plan for massive construction of nuclear infrastructure. The Messmer Plan, approved in 1974, proposed to have 13 reactors (1,000 MW each) in 1980, 50 (900–1,300 MW) in 1985, and 100 at the turn of the century.[21] The ultimate goal was to meet 100% of the French demand for electricity (*Tout Nucléaire*), and to access the international market to recover investments and reduce costs thanks to standardization and economies of scale. With such forecasts, the problem of radioactive waste became a priority. In 1979, the Agence Nationale Pour la Gestion des Déchets Radioactifs (ANDRA) was created, under the CEA, which focused its efforts on investigating the possibilities of a triple solution: surface storage, deep geological storage, and transmutation. After many studies and some partial solutions, geological storage won out with the Cigéo megaproject (Centre Industriel de Stockage Géologique), still under construction in the town of Bure (between the regions of Lorraine and Champagne-Ardenne).[22]

Currently, France has 58 operational reactors distributed over 19 plants (only the US has more), in addition to many other constructions and institutions related to the atomic option. More than 75 percent of national electricity production comes from nuclear energy, and atomic technology and know-how occupy a very important place in French exports. Even today, the nuclear sector maintains close ties with the State and has greater political and social acceptance than in other countries.[23] It is true that, from different fronts, the sector continues to be accused of elitism, opacity, and excessive costs, but it has also widely achieved tacit acceptance by paying increasing attention to information (specialized and informative), security, citizen participation, and the environment.

The origins of nuclear collaboration between Spain and France

The atom aroused a huge fascination among relevant personalities in Francoist Spain, both for its civil and its military possibilities. US president Dwight D. Eisenhower's 'Atoms for Peace' speech (1953) and the first World Conference on the Peaceful Uses of Atomic Energy held in Geneva (1955) redefined the geopolitics of the atom and forced a focus on its peaceful uses. Nuclear energy became a symbol of modernity, progress, and international integration, and all efforts aimed at its development were taken as time well spent. But the technological and financial challenge was enormous, impossible for Spain to tackle alone. Despite the propaganda that permeated the political rhetoric, resorting to foreign aid was inevitable.

A classified decree of 6 September 1948 created the Junta de Investigaciones Atómicas (JIA, Board of Atomic Investigations), dependent on the Presidency of the Government and the personal supervision of the Undersecretary of the Presidency, Captain Luis Carrero Blanco. To maintain secrecy, JIA was sheltered under the umbrella of the private commercial company Estudios y Patentes de Aleaciones Especiales (EPALE, Studies and Patents of Special Alloys).[24] The company's president was the Navy Artillery Engineer José María Otero Navascués, at that time director of the Institute of Optics 'Daza de Valdés' of the Consejo Superior de Investigaciones Científicas (CSIC, Higher Council for Scientific Research) and also director of the Laboratorio y Taller de Investigación del Estado Mayor de la Armada (LTIEMA, Research Laboratory and Workshop of the General Staff of the Navy).[25] From the beginning, the training of Spanish specialists abroad figured in Otero's thinking and was on the agenda of the JIA-EPALE. Between 1948 and 1951, Otero made several trips to Europe in order to make contact with organizations and scientists of note and to probe the possibility of sending Spanish physicists for training. Faced with technological insufficiency and lack of foreign exchange, uranium was seen as an excellent negotiating asset.[26] The work carried out in the province of Córdoba (in Southern Spain) in the previous decades by the mining engineer Antonio Carbonell had generated great optimism around the Spanish uranium reserves (estimated at about 1,000 tons).[27] The echo of Carbonell's discoveries had crossed borders, thanks to his own scientific publications (more than 300), the notes of the national and foreign press, and the incursions made by delegates of foreign companies.[28] Negotiations with Italy and

Germany were at first highlighted in the external relations of JIA-EPALE, which led to a dozen Spanish scholars carrying out, in exchange for uranium and currencies, research stays at the Centro di Informazione, Studi ed Esperienze (CISE) in Milan and at the Max Planck Institute of Physics in Gottingen.[29] Very soon, the training of these scientists and engineers would move to the US, the Western epicentre of basic and applied atomic research.[30]

The first contacts with France were not easy, on account of rivalries left over from World War Two: the French condemned the presence of German nuclear technicians and scientists in Spain, while the Spaniards complained about the inclusion in the CEA of known communists and socialists such as René Lescop, a member of the executive committee of the Radical Socialist Party, and high commissioner Frédéric Joliot-Curie, a member of the Communist Party.[31] France did not hide its interest in Spanish uranium, as it had just begun the systematic exploitation of its deposits and still had few reserves (about 300 tons in 1951, mostly from La Crouzille, Limousin).[32] But the first suggestions of collaboration were settled by evasion and negativity by both parties.[33] Spain rejected the French request to visit the Spanish mines of Sierra Albarrana, in Córdoba, using as an excuse the poor state of communications and water and electricity supplies. And the CEA, for its part, refused the admission of Spanish scholars in the newly opened Saclay Nuclear Research Centre, indicating that the *stages* (internships) for foreigners were extremely limited and required numerous previous steps.[34] Despite these initial difficulties, Otero did not envisage rejecting collaboration with France at any time. On the contrary, he considered it 'very fitting and interesting' to have the CEA in the Spanish nuclear program, and expressed his intention of intervening personally to achieve a change in attitude.[35]

In 1951, in a climate of less international secrecy, the Junta de Energía Nuclear (JEN, Nuclear Energy Board), successor to JIA-EPALE, was founded by decree-law. It established its headquarters in Madrid (Moncloa-University Zone) and fully maintained the JIA team, then composed of six doctors, eight engineers, and sixteen graduate students (in addition to some temporary collaborators).[36] The presidency was assumed, successively, by Juan Vigón Suerodíaz (1951–1955), Eduardo Hernández Vidal (1955–1958), and José María Otero (1958–1974). Unlike the JIA, the JEN considered its public face to be necessary, since similar commissions had been established in many countries, 'with powers as broad as exceptional', and international harassment towards Spain had virtually ceased.[37] The JEN covered all activities related to nuclear energy: uranium mining, training, research, safety, advice, and the production and distribution of isotopes. Foreign assistance and training of Spanish specialists in foreign centres of excellence continued to be a priority.[38]

Spain and the US signed a nuclear cooperation agreement in 1955, which regulated the sending of the JEN physicists, engineers, and technicians to the large laboratories of Argonne (Chicago), Oak Ridge (Tennessee), Los Alamos (New Mexico), Berkeley and Stanford (both California), and the Massachusetts Institute of Technology. American knowledge and expertise decisively marked the JEN's first years. The US became the nuclear reference for Spain, that is, the first supplier of equipment (experimental reactors, particle accelerators, computers, etc.), technology (headed by Westinghouse and General Electric), financing (especially the Export-Import Bank) and propaganda (books, documentaries, exhibitions, etc.). As in the rest of the Western Bloc, while the US government obtained, in exchange for its help, permission to inspect Spanish nuclear activities and confirm that there were no diversions to military applications, US major private companies began making contacts to prepare the export of civilian power plants.[39]

From the mid-1950s onwards, nuclear relations between Spain and France advanced in giant steps. It influenced the change of government in France and the dismissal of Joliot-Curie as the head of the CEA (for his arguments in favour of the Soviet Union and against atomic armament). It also influenced the continuation of French interest in Spanish uranium reserves (approximately 600,000 tons of ore in 1957),[40] although French production had multiplied after starting to exploit the rich deposits of Niger and Gabon.[41] And it influenced the common will to reduce the weight of the US in Spain, which had intensified after the 1953 Pacts.[42] But the most decisive aspect was the friendship between José María Otero and Bertrand Goldschmidt, director of International Relations of the CEA and expert in the chemistry of plutonium (in addition to being a former member of the Resistance pursued by Vichy). Otero and Goldschmidt had met for the first time in 1951 at the uranium factory in Le Bouchet, for which Goldschmidt was responsible. Since then, their friendship prevailed over their ideological differences. They maintained an uninterrupted correspondence, organized professional and personal meetings, and spent the summer together in Marbella (South coast of Spain) with their respective families.[43] Otero and Goldschmidt shared, in addition to great nuclear optimism, the determination to nationalize the whole fuel cycle and so break free of US control. For this, they considered it essential to promote the use of natural uranium (of national production) instead of enriched uranium (under US monopoly).[44] Goldschmidt opened the doors of the CEA to Spain and interceded to facilitate its entry into several European forums, specifically the European Atomic Energy Society (SEEA), of which Goldschmidt was president, and also the OCDE European Nuclear Energy Agency (ENEA) and the Conseil Européen pour la Recherche Nucléaire (CERN). Together they came up with numerous bilateral projects; some saw the light of day, such as the Vandellós 1 nuclear power plant, which we will talk about later, and others did not come about, such as the creation of a Spanish-French Institute of Higher Scientific Studies.[45] For their role in advancing bilateral relations, they received the highest protocol awards (Goldschmidt the order of Alfonso X in 1960 and Otero the *Legion d'Honneur* in 1961), in addition to *Honoris Causa* degrees from universities on both sides of the border. In 1995, Goldschmidt remembered Otero as 'one of the people I have most esteemed and respected, who became over the years a true friend for the CEA and personally for me'.[46]

In October 1956, thanks to the intermediation of Otero and Goldschmidt, the JEN and the CEA signed a bilateral nuclear cooperation agreement which regulated the channels of exchange, following in the wake of the Spanish-US nuclear agreement signed the previous year. Indeed, like the American one, it was a framework-agreement that would be completed later by specific agreements about many matters and institutions related to nuclear energy and the fuel cycle (for instance, radiation safety and protection). These agreements framed the training of human capital, a process in which visits, stays, courses, conferences, advice, manufacturing licenses, technical assistance, and supply of minerals, laboratory instruments, industrial equipment, official documentation, and bibliography came together.

In the early years, cooperation was concentrated on the initial phase of the fuel cycle, that is, the prospecting and mining of uranium. The CEA advised the JEN in the use of new geophysical and geochemical methods and in the drafting of mining legislation, playing a decisive role, according to Spanish technicians, in the preparation of work plans to be applied in the next decade.[47] The JEN financed the visits of its prospectors, geologists, and mining engineers to the mining divisions of the CEA, and also the stays of French specialists in Spain. Among the firsts, it is worth mentioning the six-month stay of geologist Enrique Ramírez, who expanded his training in the field of prospecting, geological control of samples, and calculation of reserves; learned to use new techniques (electronic equipment); and improved working conditions and safety (ventilation, mechanization).[48] Among the latter were those carried out in 1958 by the directors of Geology and Mining Research and Exploitation of the CEA, André Lenoble and Jacques Mabile, who worked in the deposits at Córdoba and Salamanca, advising on tasks such as the design of radiometric plans and the extraction of geological samples. At the same time, the Commission and its associated companies supplied the JEN, under a rental or purchase regime, with various radioactive minerals (plutonium, uranium monocarbide, thorium oxide), as well as state-of-the-art prospecting and mining equipment (gammascopes, scintillometers, gravimetric concentration towers, electronic microscopes, compressors, fans, mechanical hammers, etc.).[49] Besides, the CEA received samples of uranium concentrates for its study, and sent handbooks, films, and specialized magazines such as *L'Âge Nucléaire* to the JEN and to Spanish schools of engineers.[50] In general, material imported into Spain (registered as 'training material' or 'war material') arrived in a diplomatic bag, under a special customs regime or with a full tariff exemption.[51] Together with the equipment came French technicians and engineers in charge of assembling it and instructing on its handling and maintenance. In 1960, Otero spoke of his pleasure concerning the importance of the mining collaboration with France:

> I am very pleased to state, when talking about mining, the extraordinary and fruitful collaboration we have had with the French Atomic Energy Commission, which has meant that our engineers and our geologists could visit French laboratories and deposits, undertaking long stays, and that French geologists came to implement in Spain techniques already perfected in their country, and all this practically in a disinterested way.[52]

Apart from mining, the chemical, physical, and metallurgical treatments to obtain uranium concentrates were also a point of early interest. In the respective divisions of the CEA, the members of the JEN studied techniques for isotopic separation and nuclear purification (e.g. spectrum chemistry, leaching, coating of uranium bars) and learned to use the necessary equipment to handle highly radioactive materials (special suits, masks, airtight glove boxes). As the 1960s progressed, reactor design and fuel management took precedence over all other concerns. Thanks to American aid, the JEN had research reactors (JEN-1, Argos, Arbi) responsible for producing radioactive isotopes for medicine, industry, and agriculture, with the sites also used as training schools for technicians and engineers. But Spain aspired to equip itself with commercial reactors, using its own resources as far as possible and, if not, diversifying its foreign sources of supply. Uranium enrichment was ruled out beforehand, as it was a technological and financial challenge impossible for the Spanish economy. The problem of waste from nuclear facilities did not cause much concern at the time, being often minimized or equated with that of waste from other, non-nuclear industrial activities.[53]

The JEN, the CEA, and the scientific-technical training visits

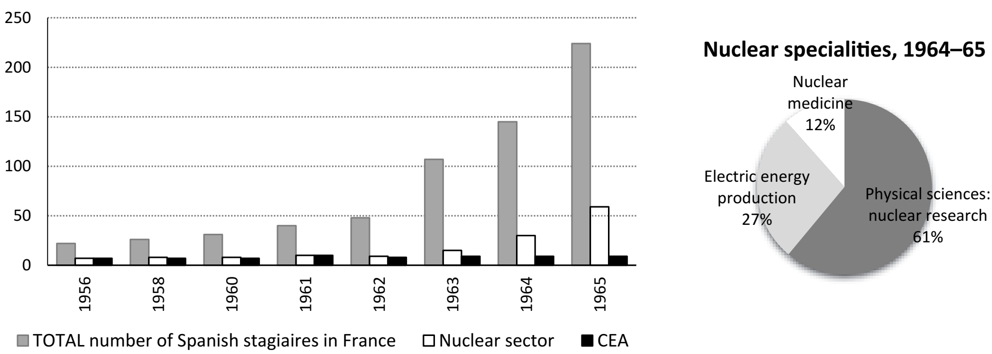
The 1956 bilateral agreement boosted visits to nuclear facilities. Virtually all the Spanish representatives, as well as top French leaders (diplomats, ministers, businessmen), visited the atomic centres of the other country at some point. Otero made an average of three trips a year, in some instances combining visits with attendance at meetings of various international organizations based in Paris. And he strongly encouraged the French to come to Spain to look at the latter's progress in the uranium cycle, and in the process do some sightseeing: '*Notre uranium est très aimable et s'installa toujours dans des lieux touristiques de premier choix*'.[54] From the 1960s, the main faculties of science and engineering schools included in their academic programs annual visits to the nuclear infrastructure of the other country, as well as exchanges of days or weeks for teachers and students.

The long-term stays began in 1956, the year in which the CEA received seven members of the JEN[55] at its facilities in Fontenay-aux-Roses (headquarters of the first research reactor, Zoé), Saclay (the French atomic academy par excellence), and the Razès School for Mining Prospectors.[56] At the beginning, the JEN and the CEA channelled practically all the exchanges: the physicists, engineers, and technicians of the JEN carried out training stays in the CEA, especially in the departments most related to mining, chemistry, and metallurgy of uranium. From 1963, origins and destinations were diversified. To the first were added the CSIC, the National Institute of Industry (INI), educational centres (involving professors and doctoral students), companies, and hospitals; to the latter, nuclear power plants, the laboratories of the Centre National de la Recherche Scientifique (CNRS), higher education centres, EDF, and engineering, construction, and capital goods companies.[57] All of these institutions were closely linked with the JEN and the CEA, as reflected in the continuous exchanges and joint projects.

Physics acquired an increasingly prominent position in the bilateral scholarship programs financed by the Ministries of Economy and Foreign Affairs of both countries. Of special relevance were the *Coopération Technique* grants from the French Ministry of Economy and Finance, which led several dozen Spaniards to attend training courses at French universities and research centres.[58] The Embassies and Consulates, the Chambers of Commerce and Industry, the French Institutes of Madrid and Barcelona, the Juan March Foundation, international organizations, and various local authorities also collaborated financially and logistically, with greater or lesser involvement depending on dates. The French physicist Claude Colin, a scientific attaché of the French Embassy in Spain and founder of the Spanish-French Association of Technical and Scientific Cooperation, played a key role in promoting French science and ministerial scholarships. Colin carried out intense mediation work between the atomic leaders in both countries, taking great care not to hurt sensibilities ('*cette susceptibilité et cet orgueil bien ibériques*') or to cause problems between the members of the different institutions due to intrusion or overlapping of functions.[59]

From 1956 to 1965, the Association pour l'Organisation des Stages de Techniciens Étrangers dans l'Industrie Française (ASTEF, Association for the Organization of Stays for Foreign Technicians in French Industry) registered a total of 152 long-term stays (minimum three months) in France of Spanish nuclear experts (17 percent of training stays of Spaniards in France, all disciplines included). By specialties, there were at the lead: 'Physical sciences:

nuclear research', 'Production of electrical energy', and 'Nuclear medicine' (with 61 percent, 27 percent, and 12 percent, respectively, in the biennium 1964–1965) (Graph 1).[60] The figures multiplied after the signing of the bilateral Agreement on Cultural, Scientific and Technical Cooperation of 1969 (renewed in 1974), exceeding one hundred annually (approximately 20 percent of the total number of Spaniards trained in France, and approximately 28 percent of the senior graduates of the JEN).[61]



Graph 1. Long-term stays of Spanish nuclear personnel in France, 1956–1965. Source: own elaboration with AGA, CEA and ASTEF data.

The Spanish *stagiaires* (interns) attended theoretical classes and were integrated into the practice teams that were in operation.[62] Starting in the mid-1950s, they became acquainted with new materials, techniques, and work patterns, and accessed safety and radiation protection standards unknown in Spain: for example, for the handling, transport and storage of radioactive material, and systematic atmospheric measurements at different times and locations. There were international dynamics that arrived at Spain via France (safety and radiation protection standards) and techniques specifically made or developed in France (spectrophotometric determinations, criteria of chemical impurities, electronic radiation detectors, etc.).[63]

To achieve the maximum benefit of the stays, candidates were required to have university degrees or the equivalent, with previous specialized courses or research stays in national laboratories also being of value. Those selected were subjected to exhaustive medical examination to rule out possible hereditary diseases and conditions that could be aggravated by radiation. In some cases, the JEN also collected certificates of good political and moral conduct, from the Civil Guard and parish priests, respectively.[64]

Otero often received letters from the *stagiaires* in the CEA, which told of their scientific achievements and personal impressions: 'They are delighted, with their treatment as well as with the experience they are getting, especially the mining engineers'.[65] On the French side, the opinions were also favourable: '*Les quelques stagiaires que vous nous avez fait l'honneur de nous envoyer à Saclay, se sont révélés non seulement d'excellents techniciens, mais aussi de véritables ambassadeurs de votre pays*'.[66] Some *stagiaires* developed successful professional careers in France, in notable centres such as the Institute of Nuclear Physics in Orsay (Oriol Bohigas), the Centre for Nuclear Studies in Strasbourg (Antoni Lloret), and the CNRS (Eduardo de Rafael).[67] But most returned to

Spain, as planned, rejoining their home centres, applying French teachings and, in most cases, coming to positions of responsibility in the Spanish atomic program. The JEN researchers Agustín Martínez (section chief of the Mining Research and Exploitation Division), Jovino Díaz (chief of the Metallurgical Plants Section), Rafael Caro (Reactors), Ricardo F. Cellini (head of the Chemistry Division), and Emilio Iranzo (Protection) are just some examples to be highlighted.[68]

The contacts of the *stagiaires* were used to invite French teachers to give courses and conferences in Spain. Thus, the Ferran Tallada Chair of Nuclear Engineering, opened in 1955 at the Special School (later Higher Technical School) of Industrial Engineers of Barcelona, regularly integrated French teachers in its workforce,[69] in addition to promoting the study trips of its students to French institutions: physicists to the Saclay Nuclear Research Centre (CEA) and the Institute of Nuclear Physics in Orsay (CNRS-University); and engineers to the University and Polytechnic Institute of Grenoble.[70] Within the framework of specialized conferences and seminars, such as the Spanish-French Nuclear Conference (Madrid, October 1963), lectures were delivered by those in the highest posts of the CEA, EDF, and French industry.[71] The training and specialization stays in Spain, seen by all as less developed in these areas, held a lesser interest for the French. Therefore, they were less frequent and less linked to learning than to the willingness to be courteous, make contacts, and disseminate French achievements and possibilities. There was still a gap between the two countries in the resources dedicated to the nuclear field. An example is the direct employment generated in 1965: 28,000 workers in France compared to 1,900 in Spain.[72]

Contacts with France contributed to the renewal in Spain of the studies of nuclear and high-energy physics, which had already begun thanks to US aid. In a few years, it went from a minority discipline, of markedly theoretical and philosophical content, to a subject more oriented to solving practical problems with large experimental equipment and interdisciplinary research groups. The nuclear power plants were the crucible in which these applied teachings converged.

From the laboratory to the market: Vandellós 1 and industrial training

In the mid-1950s, the great nuclear powers connected their first reactors for generating electricity to the grid: Obninsk in the Soviet Union, Calder Hall in Great Britain, Shippingport in the US, and Marcoule in France. Spain joined this path soon after, seeking a remedy to the scarcity on its fossil fuels and the depletion of its hydraulic reserves. Although the technology and financing had to be sought abroad, the Ministry of Industry included in the authorizations the condition of granting Spanish industry a high degree of participation in the design and construction of the plants, which favoured the training of local expertise.

French-Spanish nuclear collaboration reached its zenith at the Vandellós 1 nuclear power plant (Tarragona, on the east coast of Spain), built with UNGG technology and French public credits. It was the third commercial reactor installed in Spain, after Zorita in Guadalajara and Santa María de Garoña in Burgos, both sponsored by the US. Otero and Goldschmidt conceived the idea: a nuclear power plant that operated with natural uranium, produced plutonium for peaceful (and perhaps military) uses, and escaped from the control of the US and the International Atomic Energy Agency (IAEA).

Ministers Gaston Palewski, Alain Peyrefitte, Gregorio López Bravo, and Manuel Lora Tamayo were in charge of signing the agreements and gathering the necessary permits for its implementation.[73] In order to compensate for the cost differential with respect to the American power plants, and thus placate the misgivings of the private initiative, the French government agreed to cover around 80 percent of the plant, through loans at an average interest rate of 4 percent and repayment terms of 10 to 15 years. In fact, in its willingness to join the club of nuclear technology–exporting countries, France offered Spain additional compensations that were exceptional, both in the industrial and the political spheres: increased participation for Spanish raw materials (natural uranium) and manufacturing companies in French UNGG plants; strong support for Spain's entry into the European Economic Community (a process which remained at a standstill since 1962); and relatively free use of the irradiated plutonium, without specifying either civilian or military destinations.[74] As in the whole French nuclear program, in the case of the Vandellós 1 power plant, economic considerations were largely subordinated to political and strategic imperatives.

In 1965, a French-Spanish working group (composed of representatives from EDF and the CEA on the French side, and the JEN and the power companies FECSA, HECSA, and ENHER on the Spanish side) was established under the direction of the Catalan industrialist Pere Duran i Farell, and charged with studying the practical modalities of the operation: location, financing, legislation, and coordination. EDF, FECSA, HECSA, and ENHER shared equally in the ownership of the plant, as well as the energy produced, which would go to the Tarragona-Barcelona area and to the regions of South-eastern France.[75] In 1966 the company responsible for directing the turnkey construction works[76] was founded in Barcelona: Hispano-Francesa de Energía Nuclear S.A. (HIFRENSA). The following year, preliminary works for the conditioning of the site began: clearing and grading of land, excavation and foundation work, installation of water and electricity networks, and construction of transport infrastructure, that is, a road to join the site of the plant with the N-340 Barcelona-Cádiz highway and a railway terminal between the plant and the municipality of Vandellós. Unlike in Zorita and Garoña, the heaviest pieces were manufactured on site, the rest arriving from France by land and sea.[77] The French and Spanish conceived Vandellós 1 as a valuable training or learning-by-doing exercise, which would allow them to correct errors on the fly, and test improvements applicable to that project and future projects in France, in Spain, and in other countries: 'Work is the best school [. . .] We are all going to learn, to train and to be able to train others later'.[78] It should be noted that the plant that inspired Vandellós 1, Saint-Laurent-des-Eaux 1, was still in the construction phase on the banks of the Loire river.

The lion's share of the Vandellós 1 business went to the French companies, specifically the 25 construction, engineering, and capital goods firms integrated into the Groupement des Constructeurs Français (later the Société pour l'Industrie Atomique, SOCIA), which had been created in order to submit a tender to build the plant.[79] However, Spanish companies were able to obtain numerous construction and maintenance contracts: civil works, supply of classical electro-mechanical equipment, and fabrication of reinforced concrete for the pressure vessel, mainly. There were companies that arose from the fever of the nuclear business, and others that adapted to it, diversifying, and modernizing their production. There were companies that had worked in Zorita and Garoña, and others that did so for the first time on Vandellós 1.[80] Overall, the participation of the Spanish industry exceeded 40 percent (42 percentaccording to HIFRENSA and 40.8 percent according to the Spanish Atomic Forum).[81]

During the five years that, as required by the planned schedule, the Vandellós 1 construction work lasted, SOCIA, EDF, and the CEA organized training courses and carried out quality controls on pieces that were invoiced from Spain. French experts regularly travelled to Tarragona to instruct workers in equipment management and safety, relying on regional circles of the *Alliance Française* to solve language problems.[82] The French delegates understood the premise of not boasting superiority: 'The Spaniards are proud and sensitive [...] Engineers must be treated equally, as first-rate engineers, and not dispatched with generalities and kind words'.[83] At the same time, several Spanish technicians made stays in the CEA and EDF units to learn about the operation of UNGG reactors, in power plants or simulators. Let us mention, as an example, the Standards Group of the Security Section of the JEN, directed by Manuel Perelló Palop. Between November 1968 and November 1969, Perelló and his team attended seminars, visited the French facilities, and participated in the solution of problems raised by the reactors of Saint-Laurent-des-Eaux 1 and 2. Upon their return to Spain, they were given responsibility for the safety of Vandellós 1, in collaboration with the CEA.[84]

The building of Vandellós 1 was a complex process, which had to be reviewed often to address security issues and achieve a better adaptation to the particularities of the land. Consequently, several modifications were registered with respect to the initial design, which were then exported to the French plants. Thus came about the installation of a shell break detector, the improvement of the vessel's clamping system and thermal insulation, the enhancement of the descaling of combustible elements, and the integration of the cooling circuit in the concrete pressure vessel to reduce the risk of leaks.[85] The instruction, in Spain and in France, of the more than 300 permanent workers of Vandellós 1[86] continued during the entire operating time of the plant.

Local personnel gradually internalized the talent required to build and manage a nuclear power plant: they learned to use new materials, to transport large equipment and dangerous substances, to implement rigorous quality controls, to handle electronic and computer equipment, and to comply with international standards of radioactivity protection, surveillance, and security. Thus, in Zorita, Garoña, and Vandellós 1 – the 'first-generation' Spanish plants – the experts were trained who would later build the 'second-' and 'third-generation' plants, where turnkey contracts gave way to more balanced formulas in which Spaniards and foreigners shared the design and construction of the work and participation of the Spanish industry exceeded 80 percent.[87]

The Vandellós 1 nuclear power plant operated from 1972 to 1989, generating a total of 55,647 GWh that basically fed the metropolitan area of Barcelona. France supplied most of the fuel elements, manufactured in large part from French natural uranium of African origin (which was cheaper). In addition, France received the plutonium irradiated in the reactor for reprocessing at the Marcoule and La Hague sites (part stayed in France, and part returned to Spain).[88] In 1989 there was a fire in the turbine room that affected the refrigeration equipment and spread to the control room, causing the loss of control of the reactor for half an hour. It was the most serious nuclear accident ever in a Spanish plant, although it did not involve the activation of any nuclear emergency plan and went virtually unnoticed by the public.[89] In 1990 the Spanish Ministry of Industry and Energy revoked the operating permit granted to HIFRENSA, and the following year, considering the repair uneconomical,[90] the long and complex process of dismantling began, which is still continuing. Those responsible for the reactor were brought to trial, accused of not having applied the improvements that the Spanish Nuclear Safety Council had been demanding since 1986. They were acquitted.

HIFRENSA was in charge of the first phase of the dismantling, that is to say the unloading of the reactor, afterwards passing the baton to the Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA, National Radioactive Waste Company). All the permanent workers of the plant participated in the dismantling, later being able to choose either being relocated to other nuclear facilities or taking advantage of favourable redundancy and pre-retirement agreements. The firms that once built the plant also participated in its dismantling, along with new ones such as Empresarios Agrupados, Nusim, and Geocisa. This was again an excellent learning and business opportunity, both for France, which had only closed the UNGG reactors at Marcoule and Chinon, and for Spain, which faced its first major technological challenge of dismantling a nuclear power plant. Nuclear engineers from both countries identified improvements in the process that became part of future protocols, especially in matters of safety, material recycling, and reuse of facilities. Currently, waiting for the reactor's activity to decrease and the dismantling to be completed, ENRESA has built the Mestral Technological Centre in the former facilities of Vandellós 1; the centre hosts international meetings, organizes courses, monitors the behaviour of the internal structures of the reactor, and develops, in collaboration with other entities, scientific and applied research programs in new technologies, materials, and processes, with an eye on future decommissionings.[91] Regarding the waste from Vandellós 1, those components with low and medium radioactivity were stored and treated in Spain, while those with high radioactivity were sent to France, where they will stay until Spain builds its controversial Centralised Temporary Storage and thus can stop paying the huge costs for storing them in France. It is practically impossible to know the price of dismantling Vandellós 1, given the opacity and diversity of the available sources and figures. Without a doubt the construction costs have been exceeded, although competitive experience has also been acquired that has favoured, and will favour, other national and international decommissioning projects, with externalities for various sectors and companies.[92] In the next two decades, some 400 reactors in the world (5 in Spain) will end their useful life and begin dismantling.

The case study of Vandellós 1 has allowed us to identify two other 'made in France' teachings: On one hand, the concern about the aesthetics of the plants, which due to their need to be near to water courses are usually located in places of high landscape interest (the Mediterranean Sea and the Costa Dorada in the case of Vandellós 1). Claude Parent, a disciple of Le Corbusier, designed the French plants of the 1960s and 1970s, paying attention to the harmonization of buildings and landscape, and the future reuse of physical structures.[93] Antonio Bonet Castellana, also a disciple of Le Corbusier, reproduced the French schemes in the architectural design of Vandellós 1 (civil works and housing for plant workers, mainly).[94] On the other hand, EDF advised HIFRENSA and

ENRESA on the information and image campaigns that, as in the French plants, were organized in Vandellós 1 to counteract the anti-nuclear movement and present the 'friendly face' of nuclear energy.[95]

Encouraged by the success of Vandellós 1, France participated in all public tenders to build second- and third-generation nuclear power plants in Spain. The prospects of the Spanish Energy National Plan of the early 1970s were tremendously encouraging: 40 reactors planned and 20 preauthorized for their imminent construction.[96] Having abandoned UNGG technology, Framatome offered PWR-type plants. To pave the way, the planners created a subsidiary in Spain (Framatome Proyectos Industriales S.A.), sought alliances with local partners (Empresarios Agrupados, Equipos Nucleares), and tried to intervene in the drafting of the calls to orient the technical specifications to their advantage.[97] In the nuclear boom that followed the oil crisis, new fronts of cooperation emerged: first, the construction of fast breeder reactors, capable of producing their own fuel and generating up to 70 times more energy than ordinary reactors. In successive meetings, organized alternately in Madrid and Paris, the French authorities studied the sale of a *Phénix*-type reactor (maximum 450 MW) or *Superphénix* (1,200 to 2,000 MW) to Spain.[98] The first one had already been connected to the grid, and the second one was under study at the CEA. Another front of understanding was the joint exploitation of uranium in Niger (deposits at Akouta and Akokan) by Empresa Nacional del Uranio S.A. (ENUSA), a subsidiary of INI, and its French counterpart Compagnie Générale des Matières Nucléaires (COGEMA), belonging to the CEA. Also fundamental was the cooperation in the enrichment of uranium, which had ceased to be a monopoly of the US. Spain signed up, through ENUSA, for 11.11 percent of the shares of the European Eurodif consortium, which had been founded in 1972 to manage an enrichment factory (by gaseous diffusion) in Tricastin (France).[99] Finally, the storage of waste and the application of radioisotopes to medicine and agriculture were explored. All these processes involved the signing of technology and technical assistance contracts, and the continuous exchange of experts over the Pyrenees. The agreement of 1956 was renewed in 1982, in order to ratify traditional areas of cooperation and include new ones, such as fusion reactors, waste treatment, and landscape recovery of old mines and nuclear facilities. More than twenty-five years later, the training of qualified personnel continued to occupy a prime place in these coordinated activities, with the addition of having become a much more balanced and bidirectional process than originally.[100]

But things did not go as well as the French expected in every respect. After Vandellós 1, France did not carry out any other major operation in the Spanish nuclear program, a combined effect of the nuclear moratorium decreed by the government in 1983 (only 10 reactors finally connected to the grid) and competition from other foreign countries. The second- and third-generation Spanish plants that saw the light of day were attributed to the US and Germany (Westinghouse took over Vandellós 2), whose offers exceeded the French ones in terms of cost, quality, safety, and/or guarantee of supply.[101] The moratorium weighed down on the fast breeder projects and forced to revise downward the orders placed with Eurodif. But French-Spanish nuclear cooperation, far from disappearing, has continued to be present in the scientific-technical and industrial fields, as evidenced by the numerous scholarship programs and bilateral research projects, as well as business associations to undertake industrial missions in Spain, France, and other countries, especially in Latin America and Asia. Today the issue of radioactive waste is a priority: ENRESA and ANDRA maintain powerful channels of exchange, which are reflected, among other aspects, in the interchange of specialists and the joint writing of preparatory studies for their respective national plans. Thus, the Spanish storage centre of El Cabril (medium and low radioactivity waste) was built in the image of the French centres of La Manche and Aube, and ENRESA's studies on individualized temporary storage, centralized temporary storage, and deep geological storage (highly radioactive waste) show a clear (and declared) French mark.[102]

Conclusions

The nuclear sector acted as an advance frontier for the international integration of Francoist Spain, expanding the external forums in which the country was welcome despite its dictatorial regime and its low level of economic development. Foreign assistance, in its various forms, was decisive in the formation of the teams in charge of nuclear science, industry, and technology in Spain. Teaching-learning processes, initiated during the toughest years of the autarchy, were consolidated and intensified in the following decades, as the industrial applications of the atom advanced. Scientists, engineers, entrepreneurs, diplomats, military personnel, and policy makers all converged in these processes, spurred on by the great challenges and opportunities derived from the new technology. In the end, sufficient expertise was accumulated to achieve a relevant place internationally in specialties such as physics, engineering, and construction.

From the analysis of the training of Spanish nuclear sector personnel in France, five large conclusions can be drawn: 1) *The prominence of the States*. Although private initiative was always present, the main actors of the processes analysed here were the States, which approved the rules; contracted the macro-projects; and prioritized political, geostrategic, and economic interests over ideologies. In Spain, the influence of the JEN decreased from the 1960s for the benefit of the private initiative, but in France the CEA, EDF, and the powerful nuclear lobby (state or para-state) have kept their sway until today. In any case and in the margin of the official rhetoric, internal tensions were often commonplace in both administrations. 2) *The importance of the personnel factor*, especially in the first years. By putting their scientific solvency and their vision of the future before their possible ideological differences, Otero and Goldschmidt promoted, from the JEN and the CEA, the training in France of an elite of Spanish physicists and engineers, mostly senior graduates, who occupied, or were destined to occupy, positions of responsibility in Spain. 3) *The shared learning opportunity*. The maturity of French technology was far from that of the US. France had allocated huge resources to the autonomous development of pilot experiences. And it needed to access foreign markets to make investments profitable, improve technologies, and reach the industrial stage in competitive conditions. Spain and Vandellós 1 gave the French nuclear industry a good opportunity to test processes and products, which benefited future projects in Spain, France, and other countries. 4) *The omnipresence of the United States*. In French-Spanish nuclear relations, the 'US variable' was always present. The desire to emulate the achievements of the premier world power was combined with the will for political and energy independence. French and Spanish were aware of the impossibility of replacing the US, but they found their 'second best' in each other. France increased its nuclear capabilities and Spain diversified its external options, which surely, despite all the frustrated costs and aspirations, resulted in the development of science and technology in both countries. And finally, 5) *Externalities derived from the nuclear sector*. The training of Spanish personnel in the nuclear sector continued beyond visits, stays, and specific bilateral projects: it was recycled into new economic plans and moved to laboratories, companies, and projects not directly related to atomic energy; it renewed the pedagogical approaches of teaching and research centres; and it even formed part of industrial and scientific-technical policies, processes that go beyond the goals set in this work and leave the door open to new research. Geological sciences, chemical industries, and computer engineering divisions are outstanding examples in this respect.[103]

In short, France was not in any simple sense an alternative to the US for nations seeking nuclear-related resources or support. It was unable to compete with American financial and technological offers in the nuclear sector. Nevertheless, French capital, goods, and technology products allowed Spain to diversify its economic and foreign policy options, thus reducing its heavy dependency on the US and approaching Western Europe. The training in France of Spanish nuclear personnel helped to strengthen ties between the two countries. Knowledge, techniques, instruments, experiences, and advice, as well as ways of organizing and institutionalizing nuclear development, travelled along with the *stagiaires*, generating a network with significant cross-time and cross-sectoral opportunities.

Notes

1. Turchetti and Roberts, *The Surveillance Imperative*.
2. Nye, *Bound to Lead* and *Soft Power*.
3. Theory and examples in Krige, *American Hegemony*; Krige and Barth, *Global Power Knowledge*; Oldenziel and Zachmann, *Cold War Kitchen*; Krige, "Hybrid Knowledge"; Van Dongen, *Cold War Science*; Drogan, "The Nuclear Imperative"; and Ito and Rentetzi, "The co-production of nuclear science and technology."
4. Strasser, McGovern and Judt, *Getting and Spending*; Kipping and Tiratsoo, *Americanisation in 20th century Europe*; and Edgerton, "Creole Technologies."
5. Kuisel, *Seducing the French*; Pells, *Not Like Us*; and Schröter, *Americanization of the European Economy*.
6. Adamson, "Commissariat of the Atom"; and Belot, *L'Atome et la France*.
7. Álvarez and Molero, "Technology and the Generation"; Buckley, "Business History"; Jones, *Multinationals and Global Capitalism* and "Firms and Global Capitalism"; Narula and Dunning, "Multinational Enterprises"; López, Molero and Santos-Arteaga, "Poverty traps"; Sánchez, Rosell and García, "Absorptive capacity"; and Puig and Álvaro, "La huella del capital" and "The Long-Term Impact."
8. Secord, "Knowledge in Transit"; Turchetti, Herran and Boudia, "Introduction"; Suárez-Díaz, Mateos and Barahona, "Across Borders"; Mateos and Suárez-Díaz, "Development interventions"; and Brush, *Making 20th Century Science*. There is also a broad important historiography on science and technology in the European periphery. On this subject, we refer to Gavroglu et al., "Science and Technology"; Gavroglu, "The STEP"; Diogo, Gavroglu and Simões, "FORUM STEP Matters"; and the network of scholars STEP (https://step2.hicido.uv.es/?q=node/3, accessed April 2021).

9. Presas, "La correspondencia" and "Las ciencias físicas"; Caro, *Historia nuclear de España*; Romero de Pablos and Sánchez Ron, *Energía nuclear en España*; Romero de Pablos, "Un viaje," *Las primeras centrales* and "Knowledge That Travelled"; Rubio-Varas and De la Torre, *The Economic History*; and Camprubí, Roqué and Sáez, *De la Guerra Fría.*
10. Sánchez, *Rumbo al Sur*, and "An Alternative Route?"; Hecht, *Being Nuclear*; and Sánchez and López, *Historia del uranio*.
11. "Ordonnance n° 45–2563 du 18 Octobre 1945 instituant un Commissariat à l'Énergie Atomique," *Journal Officiel de la République Française*, Sep. 31, 1945. The beginnings of the CEA in Vaïsse, "Le choix atomique" and *La France et l'Atome*; Adamson, *Commissariat of the Atom*; Reuss, *L'épopée de l'énergie nucléaire*; Foasso, "La R&D nucléaire"; and Belot, *L'Atome et la France.*
12. See Hecht, *The Radiance of France*; and Belot, *L'Atome et la France.*
13. Term coined by Simmonot, *Les nucléocrates*.
14. On the origins and development of UNGG technology, and its differential characteristics compared to competing US technologies, refer to Lamiral, *Chronique de trente années*; Hecht, *The radiance of France*; and Dänzer-Kantof and Torres, *L'énergie de la France*. Britain had also embarked on a technology similar to UNGG (Magnox reactors). Like France, it lacked the necessary industrial machinery to enrich uranium and aspired to manufacture plutonium bombs. It managed to build 11 national natural uranium plants and export a 160 MW unit to Italy and another 166 MW unit to Japan, but soon decided, at least 7 years before France, to replace natural uranium with enriched uranium. Taylor, *The Fall and Rise.*
15. France did not sign the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) until 1992.
16. Weart, *La grande aventure*; Hecht, *The Radiance of France*; and Fridenson and Griset, *Entreprises de haute technologie*.
17. Jobert and Le Renard, "Framing Prototypes"; Schneider, "Fast Breeder Reactors"; and Sauvage, *Phénix, 30 years.*
18. Pô, *Les moyens de la puissance.*
19. Dänzer-Kantof and Torres, *L'énergie de la France*, 169–174. Framatome has always been linked to the State through the CEA and EDF. PWR technology, the most widespread worldwide, was eventually used for the entire French nuclear sector (the last UNGG was closed in 1994).
20. The US did not support the development of the French *force de frappe* (nuclear strike force). However, to guarantee the adhesion of France to the Western Bloc, it received the French in its laboratories and companies, sent technical and logistic information, and guided the investigations "in negative," that is, indicating whether or not they were going in the right direction. On France-US nuclear relations, see Ullman, "The Covert French Connection"; Vaïsse, *La France et l'Atome*; Trachtenberg, "The French Factor"; Villain, *La forcé nucléaire française*; and Petiet and Colas-Linhart, *Le nucléaire vu de l'intérieur.*
21. Aykut, *Comment gouverner*, 285.
22. Lehtonen, "Megaproject Underway."
23. The French anti-nuclear movement reached its peak in the 1970s, under the leadership of independent organisations and expert groups (scientists, media, communities with nuclear facilities). It achieved some important victories, such as the closure of the *Superphénix* reactor in 1997, but in general terms it was always weaker and more dispersed than in other countries. Grubler, "The Costs of the French"; Topçu, *La France Nucléaire*; and Tompkins, *Better Active than Radioactive.*
24. Founding Act of EPALE in the Archivo General de la Administración (hereinafter AGA), Industria, box 75/08715. A reflection of the secrecy surrounding the company can be found in the letters returned in 1949 to the *Anuario Financiero y de Sociedades Anónimas de España* [Financial Yearbook and Public Limited Companies of Spain] with the seal "unknown company," AGA, Presidencia del Gobierno, box 79.

25. Otero was the great architect of nuclear energy in Spain. Because of belonging to the Navy, he enjoyed a solid position in the regime and had the full confidence of Carrero Blanco. Due to his research in the field of optics, he enjoyed prestige in international scientific circles. And because of his many trips abroad, he personally knew outstanding physicists worldwide. All those who at some time dealt with him concurred in highlighting his qualities as hardworking, enterprising, intelligent, affable, a polyglot, and extraordinarily gifted in human relations. Biographical notes in Sánchez del Río, "José María Otero"; Villena, "José María Otero"; Caro, *Historia nuclear de España*; De Andrés, *José María Otero*; and Pérez, *José María Otero*.
26. Caro, *Historia nuclear de España*; Romero de Pablos and Sánchez Ron, *Energía nuclear en España*; Romero de Pablos, "Knowledge That Travelled"; and Adamson, Camprubí and Turchetti, "From the Ground Up."
27. Spain was thus in fifth place worldwide, behind the Belgian Congo, Canada, Czechoslovakia, and the US. Comba, "Los minerales de uranio"; and AGA, Presidencia del Gobierno, BRESA files, 1948–1950, box 83.
28. For example, Alexis Yakimach, representative of the Société Nouvelle du Radium in Paris. Soler, *El inicio de la Ciencia Nuclear*, 35.
29. Presas, "La correspondencia" and "Science on the Periphery"; Romero de Pablos, "Un viaje." The continued request for foreign currencies by JIA-EPALE was met with reluctance from Suanzes, then the head of the National Institute of Industry and the Ministry of Industry and Commerce. The direct intervention of Carrero Blanco was necessary to unblock the projects. See the exchange of letters between Suanzes, Vigón, and Carrero Blanco, 1951, in AGA, Presidencia del Gobierno, boxes 59 and 83.
30. Caro, *Historia nuclear de España*; Romero de Pablos and Sánchez Ron, *Energía nuclear en España*; and De la Torre and Rubio-Varas, "American Nuclear Training."
31. Romero de Pablos and Sánchez Ron, *Energía nuclear en España*, 36; Romero de Pablos, "Un viaje," 518, Sánchez Ron, "International Relations in Spanish Physics," 23–24; and Pérez, *José María Otero*, 36.
32. 1st Five-year Plan for the Development of Atomic Energy (1952).
33. Pérez, *José María Otero*, 36.
34. The first brief visits to Saclay by senior officials of the JEN (Antonio Colino, Carlos Sánchez del Río, Luis Gutiérrez Jodra, Ricardo Fernández Cellini and José Terraza Martorell) were authorized in 1953, AGA, Educación, boxes 31/5713 and 32/18184 and Letter from F. de Rose, from the French Embassy in Spain, to the CEA, March 21, 1953, Archives du Commissariat à l'Énergie Atomique (hereinafter ACEA), FAR 2008–22-73, dossier no. 3/6, 1951–1962.
35. Report of the Geneva Conference on Peaceful Uses of Nuclear Energy, Sep. 1955, AGA, Industria, 71/8470.
36. Romero de Pablos and Sánchez Ron, *Energía nuclear en España*, 41–42.
37. Letter from the president of JIA to the Deputy Secretary Minister of the Presidency, Oct. 6, 1951, AGA, Presidencia del Gobierno, box 83. The JEN was attached to the Presidency of the Government until, in 1957, it became dependent on the Ministry of Industry.
38. Otero, "Hacia una industria nuclear"; and Durán and Pascual, "La formación de técnicos."
39. On Spain-US nuclear relations, see De la Torre and Rubio-Varas, *La financiación exterior*, "Learning by Doing" and "Electricidad nuclear"; Caro, *Historia nuclear de España*; Romero de Pablos and Sánchez Ron, *Energía nuclear en España*; Presas, "Science on the periphery"; Ramírez, *Ciencia, tecnología y propaganda*; Soler, *El inicio de la Ciencia Nuclear*; Romero de Pablos, "Poder político" and "Prensa y tecnología"; and Camprubí, Roqué and Sáez, *De la Guerra Fría*.
40. About 1,500 tons of uranium content. In the end, the exploitation of Spanish uranium was much more burdensome than expected: the geological characteristics of the deposits made the extraction difficult and provided dispersed low-grade minerals.
41. Paucard, *La mine et les mineurs*; and Hecht, *Being Nuclear*.

42. This topic has been largely explored by specialists in French-Spanish relations during the second half of the twentieth century: Sánchez, *Rumbo al Sur*; Trouvé, *L'Espagne et l'Europe*; Castro, "Génesis y transformación"; Puig and Castro, "Patterns of International Investment"; and Delgado, "El factor exterior."
43. ACEA retains part of their correspondence. During his exile in the US, Goldschmidt had participated in the Manhattan Project. Repatriated to France after the Liberation, he was one of the parents of the French atomic bomb. He probably also dealt with these issues with Otero.
44. See Goldschmidt, *Las rivalidades atómicas*, with a preface by Otero; Caro, *Historia nuclear de España*, 25, 63 and 77; and note from the Direction des Affaires Politiques, Service des Affaires Atomiques, Paris, Oct. 27, 1964, *Documents Diplomatiques Français*, 157 (2002). Argument reproduced in other countries, like India. Abraham, *The Making of the Indian.*
45. "Projet d'organisation de l'Institut hispano-français des Hautes Études Scientifiques," c. 1960s. Exchange of letters between Otero and Goldschmidt, Sep.-Dec. 1957, ACEA, FAR 2008–22-73, dossier no. 5/6, 1955–1962.
46. Caro, *Historia nuclear de España*, 25.
47. Zuriaga, Fernando, "Prospección geofísica y geoquímica del uranio," JEN-Primer coloquio de información geológica y minera de los minerales radiactivos, 1959, AGA, Industria, 71/8816.
48. Ramírez, "La prospección del uranio," and "Memoria de la Sección de Metalurgia de la JEN," Nov. 21, 1955, AGA, Industria, 71/8793.
49. Companies supplying these were: Compagnie Française des Minerais d'Uranium, Compagnie Industrielle des Combustibles Atomiques Frittés, Minerais et Métaux, SNECMA-Division Atomique, Péchiney, Air Liquide, Neyrpic, Merlin and Guerin, Saint Gobain, Rhône-Poulenc, la Société Parisienne pour l'Industrie Électrique, Alsthom and Technicatome. Information extracted from correspondence kept in the CEA and AGA Archives, several boxes.
50. Letter from Claude Colin to Jean Renou, May 5, 1962, ACEA, FAR 2008–22-73, dossier no. 4/6, 1957–1962.
51. Letter from Otero to Goldschmidt, Sep. 10, 1959, ACEA, FAR 2008–22-73, dossier no. 1/6, 1954–1962. Invoices in AGA, Industria, box 75/8716.
52. Otero Navascués, "La Junta de Energía Nuclear," 7.
53. Sánchez Vázquez, "La legitimación," 160–161.
54. Letter from Otero to Goldschmidt, Madrid, Jan. 29, 1957, ACEA, FAR 2008–22-73, dossier no. 5/6, 1955–1969.
55. These were the mining engineers Ángel García Corral, Jesús Puy Huarte and Juan Martín Delgado; and the chemists Germán Domínguez Rodríguez, Baldomero López Pérez, Tomás Batuecas Marugán and Luis Gascó Sánchez.
56. Durán, Armando, "Las relaciones internacionales y la colaboración internacional," JEN-Primer coloquio de información geológica y minera de los minerales radiactivos, 1959, AGA, Industria, caja 71/8816.
57. Schools related to military applications of nuclear energy did not receive foreigners. More details on the destination centres in "L'enseignement du nucléaire en France," special issue of *Revue Générale Nucléaire*, 5 (1984).
58. Physicists from the University of Barcelona to the Institute of Nuclear Physics in Orsay, for example. Carpio *Ciència i política exterior*.
59. Note from the Directorat des Relations Extérieures of the CEA, April 17, 1962, ACEA, FAR 2008–22-73, dossier no. 1/6, 1954–1962, and Herran and Roqué, *La Física en la Dictadura*, 221–238 and 232–233.
60. ASTEF, *Annuaire des anciens stagiaires*, Paris, various years.
61. ASTEF, 1956–1965, "Españoles en el CEA," AGA, Industria, 71/4054 and the Archives du Ministère français des Affaires Étrangères (hereinafter AMAE-F), Spain, Affaires Scientifiques et Techniques, 1969–80, vol. 1395.

62. They did not receive, like the *stagiaires* from French colonies and ex-colonies, independent lessons organized specifically for them. Le Guelte, 'La formation des étrangers,' 432.
63. Petrement, "Servicio de química analítica," 359.
64. "CEA-Dossiers des stagiaires étrangers," AGA, Industria, box 71/8585.
65. Letter from Otero to Goldschmidt, Jan. 29, 1957, ACEA, FAR 2008–22-73, dossier no. 2/6, 1954–1962.
66. Letter from Goldschmidt to Otero, Feb. 8, 1960, ACEA, FAR 2008–22-73, dossier no. 1/6, 1954–1962.
67. Information note from the French Embassy in Spain-Scientific Service, Sep. 1969, and Herran and Roqué, *La Física en la Dictadura*, 235–237.
68. "Españoles en el CEA," AGA, Industria, box 71/4054. Some of them had already been, or would go later, to the US atomic laboratories.
69. Such as the physicists Thomas Reis, Théo Kahan, Pierre Argeron, Daniel Blanc, Léon Jacqué, Paul Lacombe, and even Claude Colin. Their lectures covered a wide range of contents: the role of nuclear energy in the world, artificial radioactivity, minerals, types of reactors, fuels, industrial applications, radiobiology, safety, protection, etc. Barca, "Els inicis de l'enginyeria," 143–148 and Carpio, *Ciència i política exterior*, 26–27. Thomas Reis was also responsible for the distribution and translation into Spanish of manuals on nuclear energy. See for example, Reis, *Reactores nucleares.*
70. Barca, "Els inicis de l'enginyeria"; Carpio, *Ciència i política exterior*; and Herran and Roqué, *La Física en la Dictadura.*
71. See report and list of speakers in *Energía Nuclea*r, 29, 1964, 88–103.
72. De la Torre and Rubio-Varas, in Camprubí, Roqué and Sáez, *De la Guerra Fría*, 95.
73. Negotiation process and highlights in HIFRENSA *Vandellós 1*; Marty and Sánchez, "La centrale nucléaire hispano-française"; Sánchez, *Rumbo al Sur*, "La connexió hispano-francesa," and "An alternative Route?"; and Romero de Pablos, *Las primeras centrales*, 99–124.
74. Further information in Sánchez, "La connexió hispano-francesa," and "An alternative Route?".
75. After a year, they were joined by Fuerzas del Segre, with a minority stake.
76. In turnkey contracts, common in the construction of many other commercial reactors worldwide, the contractor assumes full responsibility for the design and construction of the plant, committing to deliver the finished work on a fixed date and with a closed price.
77. The evolution of the works, illustrated with numerous photographs, can be followed in the thirteen issues published by the magazine *HIFRENSA. Central Nuclear de Vandellós* between February 1968 and July 1972, and in the Minutes of the meetings of the Executive Committee and the Board of Directors of HIFRENSA, Archives d'Électricité de France (hereafter AEDF), box 891165.
78. "Note concernant la conduite de l'affaire Vandellós," April 10, 1967, AEDF, box 890521. Same dynamic observed in Zorita: De la Torre and Rubio-Varas, "Learning by Doing."
79. Indatom, SEEN, GAAA, Alsthom, Campenon-Bernard, Alcatel, Ateliers et Forges de la Loire, Compagnie Électro-Mécanique, Babcok and Wilcox, Stein and Roubaix, Compagnie Générale d'Électricité, Compagnie Générale de Télégraphie Sans Fil, Neyrpic, Péchiney, Saint Gobain Techniques Nouvelles, Forges et Ateliers du Creusot, Jeumont-Schneider, Ugine Kuhlmann, Société Industrielle Delattre-Levivier, Compagnie de Constructions Mécaniques Procédés Sulzer, Chantiers de l'Atlantique, Société Hispano-Alsacienne, Société Parisienne pour l'Industrie Électrique, Compagnie de Constructions Internationales and Merlin Gerin. Indatom and SEEN operated as coordinators. Contracts in AGA, Industria, boxes 8588–8589.
80. Due to the volume and number of orders, and technical assistance contracts, Entrecanales y Távora, Material y Construcciones S.A., Cimentaciones Especiales S.A., La Maquinista Terrestre y Marítima, Constructora Pirenaica, Procedimientos Rodio, Entrepose, Degrémont, Schwartz-Hautmont, Isolux and AUXIESA stand out, these being mostly subsidiaries or at least technological partners of French companies.

81. Minutes of the 14th meeting of the Board of Directors of HIFRENSA, Barcelona, Nov. 19, 1970, AEDF, box 891165 and *Boletín del Fórum Atómico Español*, 47, 1973, 5. List of the main Spanish firms in Sánchez, "La connexió hispano-francesa," 128.
82. Testimony of physicist Luis Preciado, employed on Vandellós 1. Vandellós i l'Hospitalet de l'Infant, Sep. 29, 2016.
83. "Note concernant la conduite de l'affaire Vandellós," April 10, 1967, AEDF, box 890521.
84. Romero de Pablos, *Las primeras centrales*, 119, from the CSN Archive, and "CEA-Dossiers des stagiaires étrangers," AGA, Industria, box 71/8585.
85. Romero de Pablos, *Las primeras centrales*, 114–121.
86. Their distribution in 1973 was: Management: 1, Operation: 74, Maintenance: 108, Technical control: 49, Safety and radiation protection: 24; Administration: 58, Medicine: 2. *Boletín del Fórum Atómico Español*, 43, 1973, 22. France, as other foreign countries with business in Spain, used to assign positions of responsibility to locals, to comply with Franco's legislation and in the process simplify the obtaining of official permits.
87. Rubio-Varas and De la Torre, *The Economic History*; De la Torre and Rubio-Varas, "Learning by Doing" and "Electricidad nuclear"; and Camprubí, Roqué and Sáez, *De la Guerra Fría*. The knowledge and skills acquired greatly influenced the modernization and internationalization of domestic service industries and engineering firms (i.e. Tecnatom, Sener, Equipos Nucleares, Empresarios Agrupados and Walthon Weir Pacific-today Ringo Válvulas), to the point of developing their own technology and conquering foreign markets. See Álvaro, "The Globalization of Knowledge"; Álvaro, Puig and Torres, "Managing Foreign Knowhow"; and the successive volumes of the current monthly journal *Nuclear España. Revista de la Sociedad Nuclear Española*.
88. According to French documentation, it was agreed that Vandellós plutonium could be freely used by both parties, as long as it was not made available to third countries and a *partial* CEA supervision was allowed (my italics). "Contrôle de la centrale nucléaire franco-espagnole," AEDE, box 891165. Vandellós plutonium was therefore out of international control until the 1980s. It seems that, like the CEA, the JEN considered its possible use sometime in not only civil but also military programs. Velarde, *Proyecto Islero*. Spain signed the NPT in 1987 (after accepting the safeguards agreements with the IAEA in 1981 and Euratom in 1985).
89. The accident reached a level of 3/7 (*major incident*) on the INES (International Nuclear Event Scale) scale of the IAEA. The press published informational notes of just 100 words, in which all risks were minimized.
90. The accidents at Three Mile Island (1979) and Chernobyl (1986) had increased safety requirements (costs), especially for natural uranium reactors.
91. ENRESA, *Central Nuclear de Vandellós I*; and CSN, *Las centrales nucleares españolas* and *Desmantelamiento y clausura*.
92. For instance, ENRESA has collaborated with the Italian SOGIN and the Argentine CNEA organizations on decommissioning projects like Vandellós 1. ENRESA, *Central Nuclear de Vandellós I*, 60.
93. Parent, *L'architecture et le nucléaire, Les maisons de l'atome* and *Les totems de l'atome*.
94. Gonzalvo, Ródenas and Zuaznabar, "Centrales nucleares y patrimonio."
95. García, *La Catalunya nuclear*. An example is the exhibition "Vandellós 1. La obra que cambió el municipio" [Vandellós 1. The work that changed the municipality] organized by ENRESA in 2011.
96. De la Torre and Rubio-Varas, *La financiación exterior*; and Rubio-Varas y De la Torre, *The Economic History*.
97. "Coopération nucléaire avec l'Espagne," note of the Direction Générale des Relations Culturelles, Scientifiques et Techniques, Jan. 28, 1976, AMAE-F, EUROPE, Spain 1971–1976, vol. 421.

98. The Minutes of the management board inform about the most assiduous participants: CEA, EDF, Technicatome, Alsthom and the group Fives-Cail-Babcockon on the part of France; and JEN, ENDESA, ENHER, SENER, AUXIESA and Equipos Nucleares on the part of Spain, AEDF, box B0000469386.
99. ENUSA's origins and first years of activity are covered in detail in Sánchez and López, *Historia del uranio*, ch. 4.
100. "Les relations industrielles franco-espagnoles," note from the Ministère du Redéploiement Industriel et du Commerce Extérieur, Paris, Oct. 9, 1984, AMAE-F, Europe, Spain, 1982–1986, vol. 5148.
101. AGA, Industria, boxes 71/10,784 to 71/10,790.
102. *Dinamo CLM. Revista de ENRESA*, 14 (special issue on 25th Anniversary of El Cabril), 33. See also ENRESA and ANDRA's corporate websites: www.enresa.es and www.andra.fr.
103. See note 87 above. On the evolution and current direct and indirect impact of Spanish nuclear industry see Acosta, *El desarrollo de la industria.*

Acknowledgements

I would like to acknowledge the editors and reviewers of *History & Technology* for their carefully reading and constructive critique of previous versions of the manuscript. Thanks also to Ben Alexander for English language editing. All possible errors or omissions obviously remain mine.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Research for this paper was supported by two grants: 1) *HAR2017-860086-R* (funded by Ministerio de Ciencia e Innovación/AEI/ 10.13039/501100011033 and by the European Regional Development Fund "A way of making Europe") and 2) *PGC 2018-093896-B-I00* (funded by Ministerio de Ciencia e Innovación/AEI/ 10.13039/501100011033 and by the European Regional Development Fund "A way of making Europe"). It has also received funding from the Castilla y León Regional Government/European Union ERDF (research project *SA241P18*).

ORCID

Esther M. Sánchez Sánchez http://orcid.org/0000-0002-8986-9911

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