● *ABSTRACT*

*In this paper, we look at how scientists construct the* national *character of their projects, to make them acceptable to governments. We also analyze how scientists adapt their projects to conflicting interests within the scientific field, and to governments' priorities defined in the political field. Our study of the construction of a tokamak suggests that agents, institutions and events can be seen as limiting factors or* constraints *on action, as well as* resources *that can be used to modify the relations of power between groups. But the ability to effect change depends in turn on the uneven distribution of symbolic (or scientific), social and cultural capital between the different agents. It is the structure of the distribution of these three sorts of capital which determines the chance of success of the many scientific projects put forward by scientists.*

# Constructing a Tokamak: Political, Economic and Technical Factors as Constraints and Resources

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**The development of scientific research** since World War II has been characterized, among other things, by the ever-increasing cost and complexity of equipment and instrumentation, most notably in 'Big Science' projects. A growing demand for work on problems of national concern, and the increasing number of opportunities for practical exploitation of research results can also be noticed. Following John Ziman, we can say that these changes 'are part of a worldwide process in which science is being transformed internally as it moves into new relationships with national economies and polities'.[1] As sociologists of science, our interest lies currently in how scientists, given this new context of experimental practice, obtain research money for major projects that could not be funded by other than

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government sources. In this paper, we will look at how scientists construct the *national* character of their projects to make them acceptable to governments. We will also look at how scientists adapt their projects to conflicting interests within their scientific community and to the governments' priorities.

Before analyzing the evolution of the strategies used by scientists to obtain funds for the construction of a tokamak at Varennes near Montreal, however, we will present the sociological framework used to understand the differences between the kinds of scientists involved in small- and large-scale experiments.

In order to understand the sociological consequences of the advent of Big Science or large-scale experiments, we argue that the social space constituted by all kinds of agents and institutions is not homogeneous. It is composed of many relatively autonomous spheres, or fields, which function as different games with their own rules and stakes.[2] Social agents socialized to live in a particular field can rarely transfer easily their skills and knowledge directly to another field. To use Pierre Bourdieu's concept, their *habitus* is the product of a trajectory in a particular field and can hardly function outside it. Each of these fields, and the relations between them, are the product of a past history of social relations and, in this sense, the system is a social construction. It is this heterogeneous social structure that forces agents who want to circulate outside their native field to adapt their discourse and practices to the implicit rules of that field. In the case of science, scientists must appeal to the political field to legitimate their demands and gain funding, and must convince politicians and administrators of the national interest of their projects. To do this, they must refer to the typical stakes of this field by talking, for example, of the 'national interest' or 'economic impact' of their projects. This suggests a strong sense in which to talk of 'translation of interests', but this sense completely reverses the use of this term by Callon and by Latour.[3] They tend to smooth the passage from one field to another as if it were a natural move made by scientists, and that there were no barriers between fields. Nevertheless, the existence of distinct subcultures, corresponding to different fields and generating particular kinds of cultural and social capital, suggests that there is a barrier (and a cost) to entry in any field.[4] The heterogeneity of skills needed to circulate in more than one field also helps explain the fact that in the era of Big Science the personality of the 'manager' with skill in public relations has taken the lead over the myth of the shy and socially misfit scientist. Whereas the latter could easily survive and hide in the field of science, only the former could be adept in the field of politics. In other words, a transformation of the structure of the field is accompanied by a transformation of the habitus required to play in the field.[5]

Thus, at the general level of the habitus of the social agents (by which we mean, following Bourdieu, the set of acquired schemas that structure practices as well as the evaluation and perception of practices),[6] there is already a difference between table-top experiment and Big Science: when the projected experiment can be done — as is still often the case – with a budget and a set of apparatuses that can be obtained simply by playing the usual rules of the scientific field (asking grants from ordinary peer-review organizations like NSF in the United States or NSERC in Canada), the social skills of the scientists can still be relatively limited.

On the other hand, when the project involves the necessity of obtaining government funds outside the usual soft-money agencies, there is a necessity for the scientists to be much more than just scientific researchers. As shown by Smith in his history of the American Space Telescope, scientists in Big Science must play a wide variety of different roles: administrators, lobbyists, 'coalition builders', economists, engineers, and so on.[7] Agents who possess appropriate social relations (social capital), and an implicit or explicit knowledge of the rules and manners (cultural capital) which defines appropriate behaviour in fields other than science, are required to do the job. In other words, whereas intellectual capital can be sufficient to construct a table-top experiment, this capital must be supplemented by social and cultural capital when one wants to enter the world of Big Science. We don't know to what extent these requirements influence the content of the knowledge produced — whatever that means — but they certainly transform dramatically the kinds of social agents who can fit into the scientific enterprise.

Our study of the process that led to the construction of the Tokamak de Varennes (TdeV) shows how the 'national' character of a project, and also its relevance to the country's needs, are the result of negotiations and rhetorical constructions by the scientists who want it to become a reality. These negotiations are, however, severely constrained by the habitus and the structure of the social, cultural and intellectual capital possessed by the different agents who, given this distribution, do not have equal chances of winning in a given environment, or of adapting themselves to a changing environment.

The new practices linked to the need for money to build apparatus and support laboratories can be traced back to the nineteenth century, first in chemistry and, later, in physics. Looking at the fund-raising attempts of Humphry Davy between 1799 and 1810 to support the expansion of his electrochemical laboratory, June Z. Fullmer shows that Davy was successful in arguing for the great potential of the results he could produce in a new laboratory, and that he 'had learnt to deploy the patriotic and religious rhetoric of his time to manipulate and secure the interests and patronage of the people who had money'.[8]

In the 1950s and 1960s, the strategies used by American high-energy physicists to obtain the funding of large particle accelerators were, in a certain way, similar to those of Davy. They were able to argue that new and bigger accelerators would allow them to make discoveries more important and more interesting than the ones they made during and immediately after World War II. Highlighting the prestige of being first to make these discoveries, they deployed a powerful 'patriotic' rhetoric. Part of this patriotic rhetoric was also an insistent recall of the important military contribution of high-energy physics laboratories in terms of weapons development.[9] Scientists learned to adjust their strategies to the new circumstances in which they found themselves, and successfully to link their own objectives with the national purpose.[10] To carry on their work, high-energy physicists needed new machines, more energetic and more costly, which necessitated larger staff and larger laboratories. Meanwhile, the military establishment was willing to support new accelerators that were a source of scientifically trained personnel who, while 'hunting' particles, would at the same time work on the development of new weapons and could be rapidly mobilized in times of crisis. Finally, the accelerators themselves could be turned into instruments of war in case of need.[11]

In this kind of process, a wide variety of social networks meet and interact, and the logics at play are numerous. Thus, to understand the complex and fluid ties between individual and institutional agents, one needs a detailed analysis of processes whereby a group of scientists succeeds (or fails) to impose a given research agenda. For us, as for the Study Team for CERN History, this methodological approach is essential since the timing of the process is important, given the possible emegence of unexpected phenomena that may alter the position of the various agents.[12]

The events described in this paper extend between 1970 and 1980, a period during which the development of fusion techniques based on the *inertial* confinement of charged particles was a top priority among government officials in Canada. These events, however, finally led to the construction by a group of Quebec scientists of a *magnetic* confinement apparatus, a tokamak, in Varennes, near Montreal. This unexpected change in the priorities of the Canadian research policy on nuclear fusion thus illustrates how transformations in governmental priorities are the unexpected results of conflicting trends and interests among the many agents involved in the decision process. Our analysis will try to describe how scientists adapted their discourses and strategies to a changing situation, and explain why the reversal of priorities between inertial and magnetic confinement came about.

## Fusion Canada: A 'Canadian' Programme Initiated in Quebec

In Quebec, thermonuclear research began in 1968 with the creation of the Hydro-Quebec Research Institute (IREQ). It quickly developed following the opening in 1970 of the Energy Research Center (ERC) of the National Institute for Scientific Research (INRS).[13] The ERC's general mandate was 'the teaching and development of research on energy conversion, generation, transmission, control and storage'.[14] Nevertheless, scientists tended to concentrate in the area of plasma physics, and on both aspects of thermonuclear fusion: inertial (using high-power lasers) and magnetic confinements.[15]

The creation of ERC povided an important institutional basis to what was only an embryonic and dispersed research activity, carried out at many institutions (the University of Montreal, the RCA Victor Laboratories and the Valcartier Defense Research Center). Rapidly, ERC became one of the most important Canadian research teams on plasma physics, and changed its name to INRS-Energie. In addition, close collaboration between IREQ and INRS-Energie allowed Hydro-Quebec, the provincial public utility, to acquire considerable engineering expertise in thermonuclear fusion.

INRS-Energie came into being at a time when nuclear fusion was the object of new interest as a potential energy source within the international scientific community. The pessimism of the 1960s concerning the possibilities of fusion reactors had suddenly yielded to a surge of optimism following the publication, in August 1968, of spectacular results, obtained by Soviet scientists, on a tokamak.[16] This success brought Americans and Europeans to focus their programmes on building this type of instrumentation, conceived by Soviet scientists.[17]

Inertial confinement fusion research using high-power lasers also met its first successes towards the end of the 1960s. Due to the large difference between the available laser energies (tens of joules), and the $10^7$–$10^9$ joules theoretically required to initiate fusion through inertial confinement, this process had long been considered impossible. In 1968, French and Soviet researchers produced neutrons from deuterium targets irradiated by laser. Coupled to a reduction of the theoretical value for energy necessary to achieve fusion, these results contributed to establish the pertinence, if not the necessity of pursuing research in this area.[18]

In the light of rapidly increasing budgets devoted to fusion in the major industrialized nations, which gave scientists access to bigger and more sophisticated instruments, Canadian (and especially Quebec) researchers quickly understood that they would soon be unable to make any significant contribution to the international fusion research community if they did not gain access to similar resources. A dozen scientists and engineers, working in universities and government institutions (namely IREQ, INRS-Energie, the University of Montreal, the RCA Victor Laboratories and the Valcartier Defense Research Center), therefore conceived of a Canadian programme on controlled thermonuclear fusion (later known as the FC Project). Given the sums involved, government financing was a prerequisite. Used to dealing with federal granting agencies,[19] these scientists and engineers naturally thought in 'Canadian' terms. In June 1972, they submitted to the Ministry of State for Science and Technology (MOSST), under the programme for 'spontaneous' research projects, a 'Proposal for a Detailed Study of a Canadian Programme on Controlled Thermo-Nuclear Fusion'.[20] In order to establish an agenda of major research on controlled thermonuclear fusion, the group proposed to identify the most appropriate research sectors, and to recommend specific projects and a suitable organizational structure for a programme on a national scale.[21] Headed by Gilles Cloutier, IREQ's research director, the Quebec researchers asked the federal government for a mandate to draw up a Canadian research programme on nuclear fusion.

## How a 'Quebec' Project Becomes 'Canadian'

Within the federal apparatus, this 'spontaneous' proposal started a consultation process involving various departments and agencies dealing with research and energy developments. Generally, government scientists working for the Atomic Energy Control Board (AECB), the Atomic Energy of Canada Ltd (AECL), the Department of Energy, Mines and Resources (EMR), the National Research Council of Canada (NRC) and the Department of Industry and Commerce (IC), were unsympathetic.[22]

Among the many comments, the suggestion by MOSST to open the FC Project to other provinces underlined its major political weakness: a 'national', therefore 'Canadian', project could not rely on participants from only one region. This aspect had loomed from the start, but it became more pressing when, ignoring negative comments, MOSST agreed to finance the project. For instance, in a letter sent on 15 November 1973 to Aurele Beaulnes, then Federal Deputy Minister for Science and Technology, researchers of the Electrical Engineering Department of the University of Alberta voiced their concern regarding the structure and management of the FC Project. They denounced the fact that their meetings with the Prime Minister's Office and various MOSST officials had failed to resolve their differences with the FC group. While agreeing on the opportunity to undertake the proposed study, they criticized the composition of the committee in charge of it:

> We cannot accept that [it] represents the present or historical distribution of Canadian expertise in the area of plasma research. Since it is the cited objective of the proposed study to define *Canadian goals and priorities* in the field of fusion energy development we feel that it is important to have as broad a regional representation as possible on the management committee. As it is often the case in this country these goals may be seen in a different context by Canadians in the various geographic regions of the country.[23]

According to the authors of this letter, the 'national' and representative nature of the project required the presence on the executive committee of scientists from the NRC, the AECL and major Canadian universities active in the field. Scientists based in Western Canada naturally feared that, once the study was completed, the Quebec group would be in the best possible position to transform itself into a 'Canadian Center for Fusion Research'.

To push their point, Western scientists called upon the help of their MP who asked the Minister of Science if she intended to add representatives from other institutions to the management committee. She answered that the government would create a new committee to supervise the study, and that this would include experts from federal institutions and from universities working on fusion research; but that there was 'no intention of expanding the management committee which originated the proposal to undertake the study'.[24]

The executive committee of the FC Project was composed of Gilles G. Cloutier of IREQ as president, Morrel P. Bachynski of RCA as vice-president and Brian C. Gregory of INRS-Energie as secretary, and also included Cameron Cumming of the Valcartier Defense Research Center and Guy Paquette of the University of Montreal. To take criticisms into account and assure the Canadian character of the FC Project, representatives from other Canadian institutions were appointed to the various sectorial study teams. Financed by MOSST ($154,000), the AECB ($50,000) and the Defense Research Council ($30,000), the mandate of the FC Project was made public on 12 February 1974. Its objectives were to:

> evaluate the field of controlled fusion, to describe, in light of the international situation and Canada's needs, possible action which the country could take and recommend the most appropriate program, budget and mode of operation for Canada.[25]

The committee was also to consider 'the possibility for Canada to participate in a program based on international cooperation, or not finance any research in this field'.[26] During the year-long study, participants visited thirty-one controlled fusion research laboratories world wide, and consulted with all major researchers in the field. Eighty briefs were submitted by concerned individuals or groups. The final five-volume report was submitted to MOSST a few days before Christmas 1974.

The public release of the report, in April 1975, reminds us that government agencies are always eager to give the impression that decisions have a consensual and unavoidable character, thus identifying them with purely rational actions. To do this, they write an official history. Once financing had been granted, MOSST therefore ignored the conflict-ridden process that preceded its implementation. Accordingly, the news release announced that the project had come at just the right time, enabling the government to give direction to its action in the area of fusion R&D, where in fact, the 'need' had been created by a 'spontaneous project' originating from a group of Quebec scientists; the news release also noted that the FC team had an 'obvious' expertise, whereas in fact its legitimacy had been the object of heated debate.[27]

## The FC Report, or How to Justify a Research Programme

In its report, the study group first recommended that 'Canada establish a coordinated research and development program on controlled fusion'.[28] Having studied various scenarios, the authors suggested to the government a fusion programme aimed at 'the development of scientific know-how and technological awareness'.[29]

In order to justify action, the authors had somehow to link Canada's future to fusion research.[30] Economic growth, industrial expansion, living standards and national security were all directly dependent on adequate energy supply, at a cost acceptable both on economic and ecological grounds. Predictions were that Canada's demand for energy would increase, and that existing resources and production methods could be insufficient. On these asumptions, the report did not subscribe to the CANDU solution to Canada's energy problems. While the authors agreed that the CANDU nuclear reactor and the large amount of local uranium reserves could ensure energy self-sufficiency for several hundred years, they maintained that problems linked to safety, radioactive waste and thermal pollution imposed limits on the use of this system, making it imperative to examine other energy sources. Contrary to fission, fusion used a readily available combustion material of almost unlimited supply – water – making it much safer and acceptable from economic and ecological standpoints. Incidentally, this argument is now used by the collapsing Canadian nuclear industry to convince people that nuclear reactors are ecological, and are the best solution to acid rain problems. This homology of arguments is not really surprising if one accepts, as our introduction suggests, that there are only a limited number of rhetorical strategies open to legitimate scientific and technological programmes in the eyes of the population or government officials.

The authors of the report also stressed the fact that, in 1974, it was still possible to establish technical cooperation agreements with foreign countries. Once scientific feasibility was demonstrated, however – probably around 1980, they thought – this might become much more difficult, since research results would then be jealously kept for their technological potential and market possibilities. Lacking the scientific and technological competence to use knowledge produced elsewhere, Canada could not reject or significantly delay the programme without suffering severe damage. As the report put it:

> Canada would be excluded from all information sources concerning one of the most important high technologies linked to the most fundamental industries: energy production. Any nation which allows itself to be excluded in this way from world industrial and technological progress jeopardizes its status as a leading industrial nation.[31]

The emphasis placed on national energy security closely tied into the new economic reality. Between the initial proposal of June 1972, highlighting the economic and industrial spin-offs of fusion research, and the November 1974 report, emphasizing energy security, an important event had changed public perception and brutally brought to the forefront the question of the security of energy supply: the oil crisis of October 1973. The Canadian government had promptly reacted to this event by creating a task force to rationalize federal energy R&D activities, and to make recommendations on resource allocations among the various fields of research.[32] The subsequent report resulted in the creation of the Interdepartmental Panel on Energy R&D (PERD). Composed of federal departments and agencies concerned with, or responsible for, energy R&D, PERD acted as the coordinating body for all federal research projects aimed at providing the country with 'the scientific and technological capability needed to reach energy self-sufficiency at the lowest possible ecological, social or economical cost, while optimizing industrial and quality of life benefits'.[33] Eventually, this new organism came to be an important actor in the decision process concerning fusion research in Canada.

**Choosing Priorities: Inertial or Magnetic Confinement?**

The authors of the FC Report recommended a programme including . . .

> . . . viable applied research and development activities in the field of laser inertial confinement, of magnetic confinement using tokamaks, fusion reactor materials subjected to a neutronic flux and of system engineering.[34]

A central laboratory would carry out routine activities and coordinate projects. Canadian universities and industry would be involved on the basis of specific research or building contracts. Due to anticipated operation costs (approximately $70,000,000) and to the long-term nature of this nationwide project, the committee recommended that the federal government assume full responsibility for the administration and financing of the programme, which should be managed by a federal agency having the necessary competence.

While suggesting that the government should invest in four subprogrammes, the FC Report did not favour any one of them. The MOSST Advisory Committee had the task of analyzing the document and ranking the programmes according to priorities. This committee, reporting to the minister on 25 March 1975, globally endorsed the direction and recommendations of the FC Project, but favoured a restructuring of the programme. In order to ensure a maximum return on limited resources, it recommended that activities should be concentrated in the sector most promising for Canada by capitalizing on the CANDU programme – that is, by focusing the national research programme on a hybrid fission–fusion system.[35]

The inertial confinement option was thereby the most promising. On the one hand, it allowed use of already existing Canadian expertise in the area of high-intensity lasers, and ensured important spin-offs to industries working in this field (Lumonics, Gentec, RCA). On the other hand, it was in greater harmony with the CANDU Programme. Since the development of a system using lasers would require neutron-producing machinery, the first prototypes of such a machine would have immediate applications in hybrid fission–fusion reactors, while development would continue to reach adequate values for fusion reactors. Priority therefore was given to inertial confinement.[36] Material engineering took second place, and it was suggested that no investment should be made in magnetic confinement research.[37] The never-to-be-released MOSST Advisory Committee Report therefore considerably altered the substance of the Fusion Canada Study, and would become a major source of inspiration for the federal government.[38]

The PERD, as previously noted, acted as final administrative referee on federal energy R&D projects before they were submitted to the cabinet. The absence of representatives from university or industry left it wide open to influences from the federal scientific machine headed by the NRC. Already involved in laser research, this institution was now handed the mandate to define fusion research priorities.[39] Logical from an administrative standpoint, this move was to influence the way federal authorities and university researchers would perceive the National Fusion Program, since it transformed the *national* programme designed by Quebec researchers in the Fusion Canada Report into a *federal* programme defined by the NRC, a government laboratory. Researchers who had started federal agencies thinking about fusion two years earlier were now excluded from the decision process.

To cut a long story short, the NRC never managed to convince PERD to endorse a programme that was inspired by the MOSST Advisory Committee Report and was centred on NRC's own scientific and technological expertise: inertial confinement. In order to get out of this impasse, the NRC people invited the former president of the FC Study, Gilles Cloutier, to comment on their programme. Interestingly, Cloutier said that, in addition to the fact that the proposed programme put an excessive emphasis on inertial confinement research corresponding to NRC expertise, it was more a 'governmental' than a 'national' programme. For Cloutier, a truly national programme had to include all Canadian universities and industries involved in plasma or fusion research.[40] These comments were also voiced by other researchers affiliated with universities and industries.[41] Members of PERD also thought that the NRC fusion programme was not national enough in its impact. For the MOSST representative, for example, it should have given more space to private industry.[42]

In addition to these criticisms – which reflect the structure of the Canadian scientific scene, where conflicts are more important between government and university scientists than between scientists from different disciplines –[43] structural factors played against the NRC strategy. The Lamontagne Report (issued in 1970, as the result of the Senate Committee on Science Policy) strongly criticized the NRC for having invested too much in pure research at the expense of applied research. It also concluded that too much government research was responsible for the low level of research in private industry. This analysis led the government to implement, in 1972, a contracting-out policy, forcing government laboratories to offer more contracts to industry instead of doing all their research in-house.[44] So, in addition to being perceived as a federal project, the NRC programme ran counter to the prevalent policy of diminishing the role of government laboratories in Canadian research.

Faced with this deadlock, the NRC decided to open its door to university researchers by creating an advisory committee on fusion charged wih the task of formulating a 'national' programme of research. Of the nine members, two were from Montreal-based companies (MPB Technology and CANATOM), two from Quebec institutions (G. Cloutier from IREQ and B.C. Gregory from INRS-Energie), two were from government institutions (EACL and NRC) and two from Western universities (Saskatchewan and Alberta). Following their first meeting in July 1977, they transformed the NRC programme by insisting that, in addition to inertial confinement, a programme in magnetic confinement be established with a goal of 'scientific awareness'.[45]

## The Varennes Tokamak: From Science to Technology

Between the completion of the FC Report in November 1974, and the formation of the NRC Advisory Committee on Fusion in July 1977, Quebec scientists and engineers interested in fusion had not remained idle. In April 1977, after two years of inaction on the part of government, a group from INRS-Energie and IREQ, including former members of the FC Project, submitted to Supply and Services Canada, under its Unsolicited Proposals Program, a project entitled *A Study on the Influence of Impurities, Plasma-Wall Interactions and of Micro-Turbulence in a Tokamak Type Nuclear Fusion Device*. The work was based on the construction 'of a Tokamak apparatus of modest size' capable of ensuring 'Canada the technological preparedness necessary to future more important endeavors'.[46]

According to the authors, stimulating experimental results obtained in the field of magnetic confinement, together with a better understanding of the physical principles involved, made magnetic confinement a more promising research avenue than inertial confinement. The choice of a tokamak-type apparatus was justified by the observation that the international community considered it to be the most promising piece of equipment in magnetic fusion.

Although the fact did not transpire from the proposal, the choice also took into account the ongoing power struggle in various Canadian fusion laboratories. Among the several teams active in the area of inertial confinement, four were most visible: the NRC Laser and Plasma Section, a group of IREQ and INRS-Energie researchers, the Plasma Research Laboratory of the Electrical Engineering Department of the University of Alberta, and the Plasma Physics Group of the University of British Columbia.[47] Each of these could legitimately aspire to become a Canadian Research Center on inertial confinement. Nevertheless, in terms of equipment (variety in the types and power of lasers) or in terms of manpower, none had the scientific expertise or the political leverage to win over its rivals.

In the area of magnetic confinement, however, the situation was quite different. INRS-Energie and IREQ researchers quickly understood that competition was weaker, and that they had advantages liable to get them the support of the only group active in this sector: the Plasma Physics Laboratory of the University of Saskatchewan. Its director, H.M. Skarsgard, was recognized as the most experienced Canadian researcher in the design and operation of toroïdal machines; but, compared to the Quebec team, his group was small and could not bank on concrete support from either the provincial government, the provincial electrical utilities company or Saskatchewan's high-tech industry.

Aware that Canada did not have the technical or financial means to build a large tokamak, IREQ and INRS researchers chose to focus their research programme on two problems (impurities and microturbulences), which were both pertinent on an international scale and amenable to study with a small machine. The project also included developing a system feeding the tokamak's magnetic field directly from the public electrical network. In addition to being an interesting technological and scientific innovation – contributing to the project's uniqueness on an international level – this aspect allowed scientists to take advantage of high-power facilities available at IREQ, and of its system simulation expertise. Consisting of nine physicists and five engineers, the team described itself as 'having a combined expertise, unique in Canada' in the fields of toric configuration confinement, tokamaks and stellarators, and damage to fusion reactor materials due to rapid particle bombardment. IREQ's international reputation in the area of electrical and system engineering was also strongly emphasized.[48] For the physicists, the Tokamak Project was a unique opportunity to obtain an instrument and develop a scientific programme that would capitalize on the expertise they had acquired in foreign fusion laboratories (Fontenay-aux-Roses in France, PLT at Princeton, Alcator at MIT, and so on). The instrument also would permit them to pay their ticket of entry to the international fusion research community by contributing to the growth of knowledge in this sector.

Submitted to the NRC Advisory Committee on Fusion – formed two months later, and including major agents of the Tokamak Project – the Quebec proposal was rejected for administrative reasons; the committee suggested that IREQ submit a new proposal within the NRC programme to stimulate exchange between industry and government laboratories (known as the PILP Program), and that INRS associate itself with other universities, so as to become eligible for strategic grants for universities.

The modified and enlarged version of the IREQ-INRS project proposal was ready by September 1977. Renamed *Technological and Scientific Studies on Magnetic Confinement Fusion in a Toric Device*, it now covered forty-two pages instead of seventeen. Less academic than the first, this second version clearly emphasized the project's technological advantages. The tokamak's technical parameters and the experimental agenda had remained unchanged, but were now presented differently. Described as 'scientific' in April, the programme was now 'technological and scientific'.[49] Whereas the first proposal focused on the scientific and technological knowledge of fusion, the second emphasized the development of 'expertise in Canada in the industrial sector, including electricity utilities, and in the university sector'.[50] In April, the aim was to explore in depth the fundamental physical phenomena behind tokamak performances; in September, attention was 'primarily directed toward technological problems'.[51] Finally, they said, the amended proposal with 'two technological components and one scientific component, fulfils perfectly the programme objective of developing in Canada a technological base in the area of magnetic confinement'.[52]

To further increase its legitimacy, the new proposal called on the opinion of the International Energy Agency – created in the aftermath of the oil crisis, and of which Canada was a member – stating that greater investments should be made in technological research, an area thus far neglected by the big machines. The research agenda had been planned to complement the TEXTOR programme in Julich (FRG) – coordinated by the International Energy Agency, and in which Canada could be asked to participate, according to the authors of the proposal – and other major American and European projects.[53] While increasing the chances of success, this approach restricted the number of technological choices. To be successful, scientists with limited means had to find a niche that was neglected by the big tokamaks, one that could be handled with a small one and still interest those working on the big ones. For the Quebec scientists, impurities and microturbulences met these criteria. In short, political and budgetary constraints weighed as heavily as the researchers' scientific or technological expertise and interest when it came to the choice of the technological parameters of the apparatus.

Between the two versions of the proposal, new partners had also joined the original promoters: physicists from the University of Montreal, and two private companies, Canatom and MPB Technologies Inc.

> The result of this mix, they maintained, is that the transfer of technology to those able to exploit it commercially is assured and that university researchers are tied into the solving of real problems of national concern in the energy field.[54]

In fact, the addition of these three new partners practically reconstructed the team which, in 1974, had carried out the Fusion Canada Study.[55] From a scientific and technological standpoint, adding eleven new physicists and an engineer considerably strengthened the team's expertise in the area of toric confinement.[56] The participation of IREQ, Canatom and MPB Technologies was all the more strategic, since the federal government very much wanted to see greater involvement on the part of industry and provincial governments in R&D projects.

Finally, by opening the project to researchers from other provinces the group wanted to overcome, at least partially, the problem of national representation which had plagued the Fusion Canada Project in 1972. By seeking collaboration from the only other group actively involved in toric-configuration magnetic confinement, headed by professors Skarsgard and Hirose from the University of Saskatchewan, the group effectively dressed itself in a pan-Canadian garb.

The matter of financing was also strategically addressed. Whereas the initial proposal only vaguely mentioned the possibility of a 'shared cost' project, now the sharing rules were precisely laid out in the revised proposal. By assuming a large part of equipment and manpower costs, the group would, within a three-year span, take charge of almost half the total cost of the project. The other half would come from federal institutions.[57] This contrasted with previous projects – the FC Canada Study and CNR's plans – which left the full financial burden to the federal government. This budgetary strategy took several factors into account. First, by asking only a minor contribution from the yet-to-be defined National Fusion Program, the Quebec group effectively avoided having to deal with the majority opinion prevailing in Ottawa at the time, which was more favourable to inertial than to magnetic confinement. In addition, within the larger context of Canadian science policy, the group's approach had the strong advantage of conforming to the federal contracting-out policy. By associating two high-tech industries, a provincial electrical utility company and two university-related institutions, it contained all the ingredients government officials thought were required to promote technological innovation and technology transfers from university and government laboratories to high-tech industries. Better still, neither NRC's nor Saskatchewan's researchers were able to match this offer by enrolling equivalent local agents in their programme.

## An Appeal to the Provincial Government: 'Quebec' against 'Ottawa'

Faced with the new proposal, CNR's fusion committee still remained divided over which programmes to favour. It rejected the idea of starting construction of the TdeV without having looked at the fusion-related projects submitted to NSERC's Strategic Grants Program.[58] In addition, it did not feel financially strong enough to support a facility of such a magnitude, thus taking the risk of definitely engaging in magnetic confinement before having defined the guidelines for the National Fusion Program.

Faced with this rejection, and having put all their scientific and social capital into a proposition they thought could not be rejected, the members of the group decided to play the political card and appeal to the public through the media. During a press conference, echoed in *Le Devoir* on 17 November 1977, under the heading 'Controlled Nuclear Fusion: INRS researchers accuse Ottawa of Discrimination', a spokesman of the group, Brian C. Gregory, reminded the public that Quebec had pioneered the field of nuclear fusion in Canada, and that the highest concentration of Canadian expertise on fusion was in Montreal. He deplored the fact that due to insufficient funding, the ongoing efforts would not be pursued much longer:

> Our favorable position is beginning to deteriorate. Other groups, particularly in Ontario, have begun to develop teams. Some university laboratories have even obtained research contracts in the area of fusion whereas our projects are turned-down under the pretence that the Government does not have a National Fusion Program.[59]

According to the scientists attending the press conference, the federal government's decisions represented 'a concerted effort to undermine the position of francophone researchers . . . an action against Quebec'.[60] Gregory also recalled that three years earlier, at the time of the FC Project, the federal government had taken away from Quebec the National Fusion Program file, entrusting it to the NRC, which then came up with a project favouring almost exclusively its own field of expertise, inertial confinement. The message was clear and public: the Quebec government had to intervene so that Ottawa would not concentrate outside the Province all the Canadian expertise on fusion, as had been the case for nuclear fission technology. MOSST's officials denied accusations made by INRS-Energie researchers, but they admitted, internally, being aware that this whole affair could very well be 'the cause of severe degradation of [their] relations with Quebec'.[61] The election of a separatist political party, the Parti Québécois, a year earlier in the Province of Quebec, could only further complicate the already strained federal–provincial relations.

Immediately after these events, the advisory committee drastically changed its attitude towards the Varennes Tokamak Project. Called upon to evaluate and rank the fourteen research projects received by the NRC in response to the first Strategic Grants Program competition, the committee ranked second in the 'high priority' category a $390,000 proposal submitted by INRS-Energie Director, B.C. Gregory. Although the requested budget was reduced to $250,000, this grant remained by far the largest recommended by the Committee.[62] Competitors of the Quebec project, University of Saskatchewan's STOR-II and McMaster University's 'Tokamak Simulator', were both ranked as 'non-strategic'. The CNR's decisions, however, only affected strategic grants and had no implications for the National Fusion Program, whose priorities had not yet been defined. In practice however, the Quebec project would, with this grant, be taking a lead over its competitors. But, to the CNR's Fusion Committee's great surprise, NSERC, which had the final say in the matter, refused to finance the Quebec study.[63]

This new setback was only temporary. A few weeks later, the advisory committee learned that the government was finally granting a $400,000 budget to the National Fusion Program for the year 1978–79. After discussing the Quebec proposal with M.P. Bachynski, Chairman of the Advisory Committee on Fusion and a member of the Quebec group (as president of MPB Technologies), NRC's chairman asked the committee to take an official decision on the opportunity of integrating the project within the National Program. Finally, acknowledging that the Quebec initiative 'was a major component of the National Fusion Program',[64] the Committee however added that this project should not hinder other components, notably the take-off of research on inertial confinement, so dear to the NRC.[65]

Made public in July 1978 – more than three years after the FC Report had been tabled – NRC's National Program on Nuclear Fusion was to include two aspects: laser fusion (inertial confinement) and magnetic confinement fusion.[66] A $320,000 contract was thus finally awarded to Hydro-Quebec ($120,000 under the National Fusion Program and $200,000 under PILP), 'to carry out a study for the development, within the framework of the Canadian Fusion Program, of a scientific and technological research facility on magnetic confinement'.[67] On the other hand, INRS-Energie and University of Montreal researchers were granted a $260,000 subsidy by NSERC.[68]

In spring 1980, shortly before the completion of the feasibility study, the consortium began consultations with the NRC and the Advisory Committee on Fusion in order to establish a schedule and financial plan for construction of the Varennes Tokamak.[69] On 12

March 1980, the advisory committee submitted to MOSST its recommendations concerning the National Fusion Program, including, among other things, the construction of the Varennes Tokamak.[70] Nevertheless, during a meeting of the House's Committee on Science and Technology, Minister of Science John Roberts declared that fusion research left him sceptical, and that 'a case still has to be made that Canada should be involved in fusion research in a major way'.[71] In a letter sent to the *Globe and Mail*, he added that government would rather invest in scientifically less risky R&D programmes, liable to have short- and medium-term effects on the country's energy situation and industrial development.[72]

Several newspapers reacted strongly to the minister's statement and asked the federal government to change its position.[73] In an editorial entitled 'Late for the Future', the *Globe and Mail* declared that fusion was one of the most interesting and promising energy options, and that the government's inaction in this matter was definitely going to exclude the country from the international research community. According to the editorial, the consequences of such a situation would be disastrous. On the one hand, the country was on the verge of losing to foreign laboratories some of its finest scientists and engineers working in this advanced sector, and on the other, should fusion prove scientifically and technologically feasible, Canada would not have the scientific competence or technological and industrial know-how needed to build and operate fusion reactors. He concluded: 'Mr Roberts is doing his best to make sure that in fusion, as in so most [*sic*] else, Canada is merely a branch-plant economy. If that'.[74] These were exactly the arguments put forward in the FC Report six years before. Moreover, whereas Quebec scientists were singing the song of Quebec nationalism, English-speaking newspapers were adding to it an overtone of Canadian nationalism.

These public pressures added weight to scientists' demands and resulted in a meeting between Roberts and fusion programme officials, following which the minister agreed to submit the programme to the cabinet, and promised an early decision on the part of the government. In the meantime, an answer to the minister's objections was provided by the chairman of the advisory committee, who sent him a copy of the industrial impact study carried out by the Quebec group as part of their Feasibility Study. In the chairman's opinion, this study clearly showed that the benefit of a fusion research programme did not lie only in its long-term energy potential, but also in its short-term industrial spin-offs. He added that building a tokamak in Varennes would result in the development of equipment and know-how which Canadian industry would be able to export and use in the eventual building of fusion reactors.[75]

On 16 January 1981, Minister Roberts announced that the cabinet had approved a five-year plan to build a tokamak in Varennes. The agreement stated that the NRC would invest $18.7 million in the project on condition that Hydro-Quebec would invest an equal amount.[76]

## Comparative Analysis

The consortium's final victory rested on three factors: (1) a scientific and technological programme stressing potential industrial spin-offs; (2) an active participation on the part of high-tech industries and the provincial electrical utilities company; and (3) an important and efficient political lobby.

As the history of CERN shows,[77] and as noted by Dominique Pestre in his more specific study on the second-generation accelerators, any decision involving a major piece of research equipment 'is not simply an optimal-rational choice amongst a full list of perfectly defined possibilities', but rather 'the result of a series of micro-decisions which limit future possibilities and freedom of choice'.[78] From this standpoint, the decision to undertake a national fusion programme and to build a tokamak was not the product of a choice made at a crucial moment by a given individual or group. It was no more the inescapable product of scientific knowledge in the area of fusion than the result of a will on the part of federal civil servants, concerned by energy problems, to provide the country with a 'National Program', or of the desire of Canadian fusion researchers to gain access to major research equipment. The diversity of pertinent factors, and their changing impact over time, is such that none of the agents involved could control them all and be constantly on top of the situation.

Thus, the result of any decision-making process involving several agents with diverging interests is not only uncertain, but also, in a sense, contingent in as much as it depends on the complex dynamic of the fields involved, and on the relative ability of each participant advantageously to use a given relation between the fields by adapting objectives to it – be it by recruiting new allies (like media, industries, and so on), or by changing the objectives or their formulations.

In our study, for example, TdeV scientists were able adequately to adapt their project to the new context created by an emergent phenomenon that altered the government's energy policy: the energy crisis of 1973. Taking advantage of the new priority that the federal government put on energy R&D, they were able to argue for the crucial importance of fusion research for the energy self-sufficiency of the country. A few years later, they were able to adapt themselves to the decision of the federal government – stimulated by a senate report on science policy – to put forward the participation of industries and of provincial governments as an important criterion for the support of major scientific projects. To conform themselves, they enrolled MPB Technologies and Canatom, two high-tech industries, and they were able to secure the financial participation of the provincial electrical utility, Hydro-Quebec. They also rewrote their proposal for the construction of the TdeV, insisting on the technological aspects of their research programme and the potential industrial spin-offs.

A similar process is visible in Westfall's study of the founding of Fermilab.[79] She explains that when the planning for a new accelerator began in 1960, high-energy physicists faced an altered economic, political and social context. First, a new actor emerged on the scene of high-energy physics: Midwestern physicists, regrouped in the Midwestern Universities Research Association (MURA), began to investigate new schemes for constructing machines. The objective was to have the next large accelerator constructed in their region in order to stop the traditional predominance of Berkeley and Brookhaven as big accelerator builders, managers and (almost exclusive) users. At this time, there was also a growing concern in other physics specialties, and in other fields of science, about the large share of basic research funding that was going to high-energy physics and the building of accelerators. Outside the physics community, new pressures came from a tightening budget for basic research and high-energy physics due to a worsening economy, and also from a decline in public support for science and technology. The demands of MURA physicists, and the necessity to adjust a project so expensive to the budgetary constraints of the time, made the entire high-energy physics community conscious that the next laboratory would have to be different from the previous ones. It would have to be a national facility planned and managed inside a tight budget by a board with national representation, a place where physicists from everywhere in the country could go to make new experiments.

Midwestern high-energy physicists were able to cope with this new context. Their project was planned in a way that made access to the laboratory easy for outside users. For the accelerator, they proposed a design that could produce 'maximum capability at minimum cost'. In a context of budgetary constraints, a design like this had many advantages: the cost of the accelerator remained affordable for the government, high-energy physicists could do exciting physics with it, and finally, the project permitted them to sidestep the critics of physicists in other specialties, and scientists in other fields, about the large share of the basic science budget allocated to accelerator building.

By contrast, high-energy physicists from Berkeley were unable to adapt themselves to the new context. Neglecting the pressures in favour of a truly national laboratory, Berkeley's physicists began to design and plan a new machine of their own. Physicists from other laboratories were not involved in the project, and there were no plans to facilitate use of the machine by researchers from outside Berkeley. Thus the project was particularly vulnerable to criticism raised by the Midwestern high-energy physicists, who were arguing that this way of managing big accelerators was not fair because it denied them the possibility of working on this type of machine. The Berkeley proposal could also be attacked by the Midwestern politicians, who wanted a more even geographical distribution of funding. At a more technical level, wanting a machine that would work immediately, they avoided taking any risk, and so the design of the 200 BeV accelerator they proposed was conservative and costly. In so doing, they proposed an accelerator that did not match the new funding philosophy of the US government officials who, in the face of a tightening budget, wanted 'maximum capability at minimum cost'.

Still in the domain of Big Science, the case of fusion research in the United States analyzed by Bromberg shows important similarities with and differences from our case study.[80] In the history of the fusion programme – and, in particular, in the history of the TFTR (Tokamak Fusion Test Reactor) decision – we find different groups of scientists struggling to impose or maintain as a top priority the particular kind of machine they are committed to: mirrors at Lawrence Livermore Laboratory, theta-pinches at Los Alamos Scientific Laboratory, tokamaks at Princeton Plasma Physics Laboratory and at Oak Ridge National Laboratory.[81] In this process of negotiations with government officials, the machines and research programmes they proposed had to be adapted to the government's priorities. As Bromberg puts it, the experimental design proposed by each institution took into account the 'Washington context' and the priorities of the US AEC's Controlled Thermonuclear Research Division (CTR). The experimental set had to respect the $100 million budget and, most of all, it had to be a Deuterium-Tritium (DT) experiment; this choice was considered to have greater political visibility, because it might produce power and provide opportunities to attack engineering problems of fusion reactors.

To realize the DT experiment, Robert Hirsch, the Director of CTR, chose the tokamak. Tokamaks had better plasma parameters than mirrors and theta-pinches, and Hirsch 'was personally convinced that [it] could achieve breakeven [and] be made into a workable reactor'.[82] Capitalizing on their expertise in the construction of reactors, Oak Ridge physicists were ready to get involved in a DT experiment that would also improve their position in the field of fusion. Confronted with the Oak Ridge move, Princeton's physicists, even if they were opposed to a DT experiment, had to design one and play the game if they wanted their laboratory to survive and continue to occupy a dominant position in the field.

Princeton's Plasma Physics Laboratory was in a better position than Oak Ridge, Lawrence Livermore and Los Alamos when it came to adjusting its project to the CTR priorities. In effect, Princeton's physicists had a concept that appeared to be technically and financially feasible without abandoning the possibility of producing power; they had good results with their Adiabatic Toroïdal Compressor Torus, and were the first to have success with neutral beam heating; they had a vast experience in the design and construction of toroïdal machines, and were already responsible for the Princeton Large Torus tokamak, an intermediate machine between the small tokamaks in use at the time and a DT experiment.

As was the case with the Tokamak de Varennes, this capacity of the Princeton physicists to adapt their project to the context and to governmental priorities was a crucial factor of their success. Nevertheless, there is an important difference between the two projects. The TFTR episode shows that the governmental machinery that existed to deal with the scientists' propositions in the United States limited the possibilities more strongly than was the case in Canada. For example, Bromberg describes how Robert Hirsch, CTR's director, played a major role in the TFTR decision and, as we saw before, he was able to impose rules of the game more precise than did those who affected negotiations in Canada, where nobody played a role equivalent to Hirsch, because the decision-making process was much more decentralized. This more diffuse process is also a characteristic of the history of CERN; it gives the agents more freedom in defining what their programme and machine can be.[83] Another important difference between the US and Canadian fusion programmes is the negligible role of the military establishment in the latter and its predominance in the former. This difference is all the more important since there is a tendency to take for granted the US model and see a role for the military in every important technological project, without taking into account the possibility that the US case may be more an exception than a rule.[84]

In all these cases, we see at work what Smith has called 'coalition-building' – namely, the process by which agents gain support from scientists, government institutions, universities, industries, and the like, and in so doing, build 'the coalition that would make [their projects] feasible, not only in the technical sense but also in a political sense, by winning approval for it' from the appropriate decision-making bodies.[85]

## Conclusion

Our study (as well as those of Bromberg, Pestre, Smith and Westfall) shows that attempting to establish the comparative weight of various factors involved in the final choice, as factor analysis would suggest, would be fruitless. In fact, since all the factors or forces do not act simultaneously within a fixed environment, but evolve with time, it is impossible to define a stable element that would allow one to construct a hierarchy and somehow weight each factor's impact.

Yet the qualitative and socio-historical perspective used here still allows us to identify key moments during which agents redeploy their strategies. It is on these occasions that we can identify the groups that are able to adapt their strategy to meet the new situation. In the case under scrutiny here, the year 1977 marks an important turn within the power struggle between the Varennes team and its competitors at NRC and in Saskatchewan. This turning point, however, is the result of a series of events taking place between 1970 and 1977, which considerably and *unpredictably* – though *understandably*, after reconstruction – changed the content of the National Fusion Program first proposed in 1974 in the FC Report.

This episode also suggests that agents, institutions and events can be seen as limiting factors or *constraints* on action, as well as *resources* that can be used to modify the relations of power between groups. But the ability to affect change depends in turn on the uneven distribution of symbolic (or scientific), social and cultural capital between the different agents. It is the structure of the distribution of these three sorts of capital which determines the chance of success of the many scientific projects put forward by scientists.

Although some social agents have an interest in giving an air of planning and necessity to the decision-making process – as shown by the government's 'official history' of the FC Study – we feel that the complexity of the interactions examined here should suffice to convince policy analysts, economists and sociologists that long-term decision processes are nothing but a concatenation of micro-decisions taken within a specific time frame, each of which only partly determines the next, since new and unexpected events can always occur.[86] Nevertheless, to reaffirm the role of contingency is not to say that everything is possible at every moment. On the contrary, we have suggested that the spectrum of decisions open to agents is limited by the distribution of the specific kinds of capital they possess. What we need is a model that can explain the fact that in given circumstances, scientists and engineers probably could not do *much* differently than they did. As Bourdieu notes, agents 'do not struggle freely: they struggle in a manner consistent with the position they occupy in the field'.[87] Instead of choosing between, on the one hand, a complete freedom of agents – a position that constitutes, in fact, a negation of the possibility of sociological explanation – and, on the other hand, a complete determinism that leaves no place to contingency, we propose to work at equal distance from these extremes by using concepts like habitus, capital and fields. These concepts make it possible for us to understand the limits of actions and strategies, while at the same time admitting that the emergence of new and unexpected events – that is, history – modifies the space of possible action in a field, as well as the relations between fields.[88]

## •NOTES

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1. J. Ziman, *Science in a 'Steady State': The Research System in Transition* (London: Science Policy Suppot Group, December 1987), 3.
2. See P. Bourdieu, *Questions de sociologie* (Paris: Editions de Minuit, 1980), and Bourdieu, 'The Peculiar History of Scientific Research', *Sociological Forum*, Vol. 6, No. 1 (1991), 3–26.
3. Michel Callon and John Law, 'On Interests and Their Transformation: Enrolment and Counter-Enrolment', *Social Studies of Science*, Vol. 12 (1982), 615–25; Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambidge, MA: Harvard University Press, 1987), 132–44.
4. P. Bourdieu, 'Les Trois états du capital culturel', *Actes de la recherche en sciences sociales*, No. 30 (1979), 3–6.
5. For examples of historical studies of the constitution of a field, see P. Bourdieu, 'L'Institutionnalisation de l'anomie', *Cahiers du Musée national d'art moderne*, Nos. 19–20 (1987), 6–19; Bourdieu, 'Genèse historique d'une esthétique pure', ibid., No. 27 (1989), 95–106; A. Viala, *Naissance de l'écrivain* (Paris: Minuit, 1985).
6. For more on this, see P. Bourdieu, *Outline of a Theory of Practice* (Cambridge: Cambridge University Press, 1977), and Bourdieu, *Le Sens pratique* (Paris: Minuit, 1980).
7. Robert W. Smith, *The Space Telescope* (Cambridge: Cambridge University Press, 1989), 24.
8. J.Z. Fullmer, 'Humphry Davy: Fund Raiser', in Frank A.J.L. James (ed.), *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilisation* (New York: American Institute of Physics, 1989), 11–21; the quotation is from James, 'Introduction', 4.
9. Andrew Pickering, 'Pragmatism in Particle Physics: Scientific and Military Interests in the Post-War United States', in James (ed.), op. cit. note 8, 174–83.
10. Robert Seidel, 'The Postwar Political Economy of High-Energy Physics', in L.M. Brown, M. Dresden and L. Hoddeson (eds), *Pions to Quarks: Particle Physics in the 1950s* (Cambridge: Cambridge University Press, 1989), 497–507.

11. Seidel, ibid., 497–98. See also Chandra Mukerji, *A Fragile Power: Scientists and the State* (Princeton, NJ: Princeton University Press, 1989).

12. A. Hermann, J. Krige, U. Mersits and D. Pestre, *History of CERN*, Vol. 1 (Amsterdam: North Holland, 1987); Vol. 2 (1989).

13. See *Physics in Canada: Survey and Outlook* (Ottawa: Science Secretariat, Privy Council, 1967), 314–18. See also M. Trépanier, 'La Construction du Tokamak de Varennes: Anatomie d'une décision en matière de Big Science' (unpublished PhD thesis, Université du Québec 1989).

14. Université du Québec, *Annuaire 1971–72*, 51.

15. Jean Martineau, 'Le Centre de l'Energie (CREN)', *Physics in Canada*, Vol. 27, No. 3 (1971), 46.

16. International Atomic Energy Agency, *Plasma Physics and Controlled Nuclear Fusion Research: Proceedings of the Third International Conference held by the IAEA at Novosibirsk, 1–7 August 1968* (Vienna: IAEA, 1969).

17. This new confidence was reinforced by the continuous progression of the value of the parameters obtained on tokamaks: see B.B. Kadomtsev and I.V. Shafranov, 'Fourth International Conference on Plasma Physics and Controlled Thermonuclear Fusion Research: Report on the Conference held in Madison, Wisconsin, USA, 17–23 June 1971', *Nuclear Fusion*, Vol. 11 (1971), 541–45. For more details on the socio-political context in which the American programme developed, see Joan Lisa Bromberg, *Fusion: Science, Politics, and the Invention of a New Energy Source* (Cambridge, MA: MIT Press, 1982), Chapter 9.

18. Bromberg, *Fusion*, op. cit. note 17, 184–85.

19. At this time, the Quebec programme to give grants to researchers (FCAR) had just been created, and had few funds compared to the federal NRC programme, which had been giving funds to Canadian scientists since 1917.

20. IREQ, CREN, Université de Montréal, CRDV and RCA Limited, *Proposal for a Detailed Study of a Canadian Programme on Controlled Thermo-Nuclear Fusion* (June 1972): file 1550–2, Vol. 1, MOSST, Ottawa.

21. Ibid., 12.

22. A.L. Strange, *Proposal for a Detailed Study of a Canadian Programme on Thermo-Nuclear Fusion: Summary of Comments on the Proposal* (14 November 1972): file 1550–2, Vol. 1, MOSST, Ottawa.

23. N.H. Burnett, C.E. Capjack, C.R. James, A.A. Offenberger, A.M. Robinson, H.J.J. Séguin, J. Tulip and G.B. Walker to Aurèle Beaulnes (15 November 1973), 2 (our emphasis): file 1550–2, Vol. 1, MOSST, Ottawa.

24. MOSST: file 1550–2, Vol. 1, MOSST, Ottawa.

25. Projet FC, *Projet d'étude pour un programme canadien de fusion thermonucléaire contrôlée: Rapport: Tome premier: Recommandation pour un programme canadien de fusion contrôlée* (November 1974), 1.

26. IREQ et al., *Proposal*, op. cit. note 20, Annexe A, 106.

27. MOSST, *Press Release on Fusion Canada Report* (10 June 1975): file 1550–2, Vol. 1, MOSST, Ottawa.

28. IREQ et al., *Proposal*, op. cit. note 20, 41.

29. Ibid., 51–52.

30. Under the name of 'enrolment', this rhetorical strategy is also described by Callon & Law, op. cit. note 3.

31. IREQ et al., *Proposal*, op. cit. note 20, 50–51.

32. Yves Gingras and Jacques Rivard, 'Energy R&D Policy in Canada', *Science and Public Policy*, Vol. 15, No. 1 (1988), 35–42.

33. Energy, Mines and Resources, *Science and Technology for Canada's Energy Needs: Report of the Task Force on Energy Research and Development* (Ottawa: EMR, April 1975), 8.

34. IREQ et al., *Proposal*, op. cit. note 20, 58.

35. Controlleld Thermo-Nuclear Fusion Project Advisory Committee (CTNFPAC), *Minutes of the 5th Meeting* (20 February 1975), 3.

36. CTNFPAC, *Minutes of the 4th Meeting* (31 January 1975), Appendix 1, 3. See also D.L. Rowat, *Discussion at NRC on Fusion Program*, memorandum to D.H.E. Cross (25 July 1977): file 1550–2, Vol. 2, MOSST, Ottawa.

37. CTNFPAC, 'FC Report vs Advisory Committee's Report', in op. cit. note 35.

38. Rowat, op. cit. note 36.

39. Interview with Paul Redhead (Ottawa, 6 September 1988); J.D. Keys, *Re: Energy R&D Program*, letter to Dr P.L. Bourgault (25 June 1974): file 1280–1, MOSST, Ottawa.

40. Ad Hoc Committee on Fusion, *Meeting of the Group on Thursday 12 February 1976*, 1: file 1550–2, Vol. 2, MOSST, Ottawa.

41. Letter from B.C. Gregory to Paul A. Redhead (31 May 1976): file 1491–73–6, NRC, Ottawa; INRS-Energie, *A Balanced Canadian Thermonuclear Fusion Research Program* (June 1976): file 1491–73–6, NRC, Ottawa; interview with Redhead, see note 39.

42. PERD, *Minutes of the Ad Hoc Meeting of the Panel on Energy Research and Development to Consider the NRC Fusion Proposal* (14 May 1976), 3: file 1550–2, Vol. 2, MOSST, Ottawa.

43. This opposition is analyzed by Bruce Doern, *Science and Politics in Canada* (Montréal: McGill-Queen's University Press, 1972).

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45. NRC Advisory Committee on Fusion-Related Research (ACFRR), *Proceedings of the First Meeting . . .* (Ottawa, 27 July 1977), 6–7.

46. IREQ & INRS, *Etude de l'influence des impuretés, des interactions plasma-parois et de la micro-turbulence dans un dispositif à fusion nucléaire du type tokamak*, Proposition spontanée de recherche (avril 1977), ii.

47. J. Alcock and T.W. Johnston, 'Status of Canadian Research related to Inertial Confinement Fusion', paper prepared for the IAEA Technical Committee Meeting on Progress on Inertial Confinement Experiments (San Francisco, February 1978), in NRC ACFRR, *Proceedings of the Fourth Meeting* (Varennes, 11 April 1978), Annex G.

48. IREQ & INRS, op. cit. note 46, 12.

49. IREQ, INRS, Université de Montréal, Canatom Ltée et MPB Technologies Inc., *Etudes technologiques et scientifiques reliées à la fusion par confinement magnétique dans un dispositif torique*, version modifiée (septembre 1977).

50. Ibid., 3.

51. Ibid., 4.

52. Ibid., 5.

53. Ibid., 4.

54. Ibid., 1.

55. Only Canatom Ltée was not part of the Fusion Canada Project.

56. IREQ et al., op. cit. note 49, 41.

57. Ibid., 2.

58. Created in 1977, the NSERC Strategic Grants Program aimed at bringing to the attention of scientists selected projects perceived as having national importance. Energy had been identified as a strategic site of research.

59. Quoted in Gilles Provost, 'Fusion nucléaire contrôlée: Les chercheurs de l'INRS accusent Ottawa de discrimination', *Le Devoir* (17 November 1977).

60. Ibid.

61. Andre DesMarais, *Note on INRS and Fusion Research*, memorandum to Dr H.R. Wynne-Edwards (24 November 1977), 3: file 1550–2, Vol. 2, MOSST, Ottawa.

62. NRC ACFRR, 'Report on Fusion-Related Research Proposals Submitted to NRC Program of Strategic Grants' (December 1977), 1–2, in NRC ACFRR, *Minutes of the Third Meeting* (Ottawa, 5–6 December 1977), Annex F.

63. P.W. Latour, 'Fusion-Related Projects Supported under the Strategic Grants Program', letter to C.D. Doucet (15 March 1978), in NRC ACFRR, op. cit. note 47, Annex C.

64. NRC ACFRR, op. cit. note 47, 5.

65. Ibid.

66. Comité consultatif sur la recherche touchant la fusion, 'Programme national pour la fusion' (mai 1978), 2–3, Annex to *Le CNRC annonce l'établissement d'un programme national de fusion nucléaire*, in NRC ACFRR, *Minutes of the Fifth Meeting* (Toronto, 15 June 1978), Annex D. A third research programme devoted to tritium technology was to be added to the national programme in 1982, under the leadership of Hydro-Ontario. Ironically, only inertial confinement has not yet received the same status as these two programmes, though it was always the first priority, and active research on it is going on in NRC laboratories and at the University of Alberta.

67. Contrat, Sa Majesté la Reine du Chef du Canada et Hydro-Québec (21 juillet 1980), 2.

68. J.E. Halliwell, letter to C.D. Doucet (5 November 1978), 2, in NRC ACFRR, *Minutes of the Sixth Meeting* (Edmonton, 20 October 1978), Annex U.

69. NRC ACFRR, *Minutes of the Tenth Meeting* (Montreal, 16 May 1980), 7.

70. Ibid., 5.

71. Quoted from 'Skeptical Roberts Rebuffs Researchers over Nuclear Fusion', *Globe and Mail* (Wednesday, 9 July 1980).

72. John Roberts, Letter to the Editor of the *Globe and Mail*: file 1491–73–6, Vol. 1, NRC, Ottawa.

73. See, for example, 'Refusing the Future', *The Ottawa Journal* (11 July 1980).

74. 'Late for the Future', *Globe and Mail* (11 July 1980).

75. M.P. Bachynski, letter to John Roberts (29 September 1980), in NRC ACFRR, *Minutes of the Eleventh Meeting* (Ottawa, 24 February 1981), Annex B.

76. NRC ACFRR, ibid., 7.

77. Hermann et al., op. cit. note 12.

78. D. Pestre, *La seconde génération d'accélérateurs pour le CERN, 1956–1965: Etude historique d'un processus de décision de gros équipement en science fondamentale* (Genève: CERN–CHS–19, 1987), 94. See also Pestre, 'Monsters and Colliders in 1961: The First Debate at CERN on Future Accelerators', in James (ed.), op. cit. note 8, 233–41; and Pestre, 'The Creation of CERN in the Early '50s: Chance or Necessity?', in M. DeMaria, M. Grilli and F. Sebastaniani (eds), *The Restructuring of Physical*

*Sciences in Europe and the United States 1945–1960* (Singapore: World Scientific, 1989), 477–87.

79. Catherine Westfall, 'Fermilab: Founding the First US "Truly National Laboratory" ', in James (ed.), op. cit. note 8, 184–217. The following section on Fermilab is based entirely on this paper. For a comparative analysis of the founding of Fermilab and KEK, see Lillian Hoddeson, 'Establishing KEK in Japan and Fermilab in the US: Internationalism, Nationalism and High Energy Accelerators', *Social Studies of Science*, Vol. 13 (1983), 1–48.

80. Bromberg, *Fusion*, op. cit. note 17.

81. J.L. Bromberg, 'TFTR: The Anatomy of a Programme Decision', *Social Studies of Science*, Vol. 12 (1982), 559–83. The following section on TFTR is based entirely on this paper.

82. Ibid., 565.

83. Pestre, 'Chance or Necessity?', op. cit. note 78, 482. In her comparison of KEK and Fermilab, Hoddeson also shows that differences in the policy decision-making process have an important influence on the programmes and machines finally approved: Hoddeson, op. cit. note 79, 33–36. On all these aspects, see Peter Galison and Bruce Hevly (eds), *Big Science: The Growth of Large-Scale Research* (Stanford, CA: Stanford University Press, 1992).

84. The question of the role played by the military was raised at the conference on table-top experiments. The history of CERN also shows that, contrary to the expectation of many, the military played no significant role in the birth of CERN. See D. Pestre and J. Krige, 'Some Thoughts on the Early History of CERN', in Galison & Hevly (eds), op. cit. note 83, 79–99.

85. Smith, op. cit. note 7, 4: for more details, see also Chapters 1 to 5.

86. It should be noted that recent work in economic theory using non-linear probability theory can now formalize these historically contingent processes: see W. Brian Arthur, Yu M. Emoliev and Yu M. Kaniovski, 'Path-Dependent Processes and the Emergence of Macro-Structure', *European Journal of Operational Research*, Vol. 30 (1987), 294–303; Arthur, 'Competing Technologies: An Overview', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds), *Technical Change and Economic Theory* (London: Pinter, 1988), 590–607.

87. L.J.D. Wacquant, 'An Interview with Pierre Bourdieu: For a Socio-Analysis of Intellectuals: on Homo Academicus', *Berkeley Journal of Sociology*, Vol. 34 (1989), 1–29, at 9.

88. For a discussion of these questions, see Wacquant, ibid., 10–11; and J.L.D. Wacquant, 'Towards a Reflexive Sociology: A Workshop with Pierre Bourdieu', *Soiciological Theory*, Vol. 7, No. 1 (1989), 36–37.

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