Studying tensions between imaginary spaces and concrete places: the method of paired biographies applied to scientists' laboratory lives

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Studying Tensions between Imaginary Spaces and Concrete Places: The Method of Paired Biographies Applied to Scientists' Laboratory Lives

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Abstract: *»Spannungen zwischen imaginativen Räumen und konkreten Orten: Die Methode der ‚gepaarten Biographie', angewandt auf das Leben von Wissenschaftlern in Laboren«*. Spaces and places are at the center of the science studies scholarship. Some scholars focus on the spatial circulation of written traces; others focus on the socio-cultural hierarchies reflected in the spatial organization of the laboratories. But most privilege single-case studies as their research method. While single-case studies offer the advantage of providing rich and detailed ethnographic description of spaces, they often fail to explain how imaginary spaces of science are turned into concrete social settings, often with unexpected deviations from their creators' initial purposes. This paper argues that a comparative approach, which I call "paired biographies," can help us study the tensions between imaginary and real spaces of science. This method of paired biographies is applied here to trace the attempts (both failed and successful) by two prominent physicists (J.R. Oppenheimer and E.O. Lawrence) to turn their imaginary scientific spaces into concrete places. This comparative approach, based upon paired biographies of various laboratory lives taken at different points in time, highlights the tensions between imaginary spaces of science and concrete architectural forms (themselves located in broader environments), and shows which unexpected outcomes derive from these tensions.

Keywords: Laboratory ethnography, paired comparison, gendered spaces, Oppenheimer, nuclear science.

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1. Illustrative vs. Analytical Uses of Spatial Representations[1]

Ethnographers have long studied the spatial dimension of social interactions. Their field books are usually filled with maps and photographs, which they often edit in published accounts in order to share their knowledge of unfamiliar spaces with the public. Likewise, laboratory ethnographers and historians of science often include spatial representations in their accounts of laboratory life (Gieryn 1998; Ophir and Shapin 1991; Crosbie and Agar 1998; Galison and Thompson 1998; Galison and Jones 1999). Some represent the spatial flows of written traces coming out of experiments – like graphs, texts, and documents – on a map (Latour and Woolgar 1979, 46; Knorr-Cetina 1999). Others use drawings and maps to render visible the spatial ordering of social hierarchies (between scientists and technicians, men and women, etc.) on the laboratory floor (Gusterson 1996; Gieryn 1998; Shaffer 1998). In this manner, maps are useful as far as they *illustrate* how spatial forms either connect social networks or reflect socio-cultural structures. More rarely do ethnographers include spatial representations that either complicate or contradict their arguments about the nature of social classifications and cultural boundaries.

This *illustrative* use of spatial representations is often grounded in one method: the single-case study. This exclusive use of the single-case study method has some pay-offs, as the resulting ethnographies provide rich and detailed descriptions of the socio-cultural orderings of spaces. But it also has some drawbacks. In particular, when ethnographers focus on one space and one point in time, they are at risk of essentializing the material culture, which they see operating in the specific place they discover at the time of their visit. As spaces do not keep visible the memory of past conflicts, their materiality can give the false impression of immutability: after a visit, an ethnographer may have the impression that, since immemorial ages, peasants from Algeria or the South of France, for instance, have always organized the space of their adobe in a similar way (Bourdieu 2002), or that the present space of a laboratory must reflect the socio-cultural lenses of either their founders (most likely the architects and sponsors who commissioned the new space) or their users (scientists, technicians, etc.) or both (Shaffer 1998).

In contrast to this illustrative use of spatial representations, this article purports to include the tensions between imaginary spaces and concrete places at the center of socio-cultural dynamics. Indeed, conceptually, socio-cultural analyses of spatial representations need to unpack the subject into at least two

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different terms: the imaginary spaces and the concrete places. Whereas the former might reflect economic opportunities and socially-conditioned perceptions of beauty of the architects and sponsors (Bourdieu 1984), the latter are concatenations of economic, political and social forces, which find their material realization (and their limits) in concrete spatial objects and places. The two notions are not only analytically distinct, they are also often empirically quite different: many scholars observe the unexpected differences between imaginary spaces that architects intend to build and their final actualization (Knowles and Leslie 2001).

If the single-case study is the preferred method from which to derive compelling spatial illustrations of socio-cultural systems, one needs to find the adequate method that allows social scientists to analyze tensions between imaginary and concrete spaces. Paired biographies of living spaces, or "paired biographies," as I call this method, provide such analytical payoffs. "Biography" here is to be understood metaphorically, as paired biographies reconstruct chronologically the lives of places (rather than those of individuals). As I will discuss in section 3 (after a quick presentation of the case and questions asked in section 2), the method of paired biographies draws upon the literature on methods of case selection in historical and political sociology (Hall 1986; Ragin 1987; Mahoney 2007). Paired biographies combine both a *synchronic* comparison (comparing different cases at similar times); and a *diachronic* comparison (comparing similar cases at different times), as they follow how each imaginary space of science is turned into a concrete place, and what is lost and added in the process.

2. The Cases under Study: Bucolic and Machinic Imaginary Spaces of Science

The method of paired biographies consists in sequentially conducting two paired comparisons. Here, the four imaginary spaces that are included in these paired comparisons are four different laboratories (Cavendish and Los Alamos; Radiation Laboratory and Oak Ridge), to which I add a last pair (Institute of Advanced Studies and Livermore Laboratory). One series of laboratories hosted the activities of J. Robert Oppenheimer (1904-1967); while the others were mostly the creation of Oppenheimer's colleague and sometimes competitor, Ernest O. Lawrence (1901-1958).

2.1 Bucolic and Machinic Spaces in the Era of "Big Science"

I chose these laboratories with the goal of examining how two very different imaginary spaces of science resisted a sea change in the social, economic and cultural organization of Western science during World War II. Indeed, all of these laboratories are associated with developments in the field of nuclear physics and with the wartime efforts to develop nuclear weapons. In spatial terms, World War II shifted the scientific world away from the "bucolic" world (Shaffer 1998) of the British universities (taken as a source of inspiration by many U.S. campuses), to a "machinic" world (De Gaudemar 1982; Pickering 1993) closer to the industrial organization of labor in an age of mass-production. Symbolically, research sites were exported from the traditional centers of learning to the new industrial spaces of research and development located in barren fields and hidden behind military fences (Rhodes 1986, Kevles 1978, Forman 1987).

To study the transition from the bucolic to the machinic worlds (and its limits) in nuclear laboratories, this paper follows diachronically (from the end of the 1920s to the mid-1950s) the trajectories of two pivotal nuclear scientists: J. Robert Oppenheimer and Ernest O. Lawrence. Oppenheimer first conducted laboratory work in experimental nuclear physics at the bench of the Cavendish laboratory (UK). After completing his PhD, he was hired in the physics department at University of California, Berkeley, where he first met of Ernest Lawrence (Bird and Sherwin 2006). Oppenheimer soon became head of the most famous nuclear laboratory constructed with the funds of the U.S. nuclear weapons program: Los Alamos. After he completed his job of designing nuclear warheads at Los Alamos, Oppenheimer kept working at the Princeton Institute of Advanced Studies, and he held prestigious positions at the Atomic Energy Commission until he lost his security clearance in one of the last hiccups of the McCarthy period (Mallard 2008).

Ernest Lawrence is less known to the broader public, but his importance in the development of nuclear science is no less great than the one of Oppenheimer. A professor at the physics department of Berkeley, Lawrence created the Radiation Laboratory (Rad Lab) before WWII. An experimenter rather than a theorist, Lawrence gained tremendous importance during the war after he successfully used his cyclotrons at Oak Ridge to enrich uranium (to separate highly fissile isotopes U^{235} from uranium U^{238}). After the war, Lawrence went back to theoretical analyses of matter by using bigger accelerators of particles, but soon after the construction of the H-Bomb was decided, he obtained funding for and supervised the construction of the Lawrence Livermore National laboratory. Unlike Oppenheimer, he died in the Fifties at the height of his credibility and power in the nuclear establishment.

The laboratory spaces discussed here gained symbolic status not only in the limited world of nuclear physics: considering the prestige of nuclear physics after the war, the corporate leaders of many industrial giants of postwar America, like General Motors, "looked to Los Alamos and Oak Ridge – not to automobile factories – as the appropriate models for a great laboratory […] that could provide what corporate executives considered essential outposts on the endless frontier of science" (Knowles and Leslie 2001, 2-6). How these great laboratories were created, and whether they concretely represented the imaginary spaces of science first envisioned by their founders, will be further examined in this paper.

2.2 Methodological Questions

As far as the laboratories selected are concerned, I use the method of paired biographies to answer the following questions:

Can we observe fundamental differences in the imaginary spaces of science between the selected laboratories before the war? How can we account for these differences? Do these imaginary spaces reflect broad macro-socio-cultural differences in the contexts of their creation (Victorian Britain vs. post-Great Depression America)?

As new laboratory spaces are built during World War II, did these new laboratory spaces reflect the same socio-cultural conceptions as those found in the pre-war era? Did the imaginary spaces of science in Los Alamos and Oak Ridge shape the concrete places and concrete practices found in these labor sites? How can we account for the deviations between their founders' original visions and their concrete realizations?

More generally, from the application of the method of paired biographies to these cases, can we deduct that such method of joint-paired comparisons offers analytical payoffs compared to a simple series of single-case studies? If so, what are these analytical payoffs?

2.3 Data Collected

The data collected in this paper derives from monographic studies of each laboratory that I selected for the comparison (Heilbron, Seidel and Wheaton 1981; Shaffer 1998; Hales 1997). Indeed, this paper does not aim at refining data-collection techniques but at improving our methodology of case selection in order to constitute new research objects. These laboratory monographs were produced by historians of science based on the examination of reports of scientific life by the scientists themselves and their families. Such historical data is very useful and generally very rich, as scientists pay a lot of attention to the effect that their experimental settings (including the spatial configuration of instruments) may have on the results of their experiments (Knorr Cetina 1999). Their quest for scientific accuracy explains why they record how spatial reconfigurations of their instruments might affect their results.

Historians can also cross the analysis of scientists' self-report of their knowledge practices with the analysis of private sources, like that of the families of the scientists themselves (Fermi 1954), who often produce first-hand reports of the spaces of science when they visit their father/husband/brother, etc., and/or when the space of science is embedded itself in a concrete place where the family coexists with workers. And last, historians and anthropologists of science not only rely on written self-reports by scientists and their friends/family members but also use photographs (Latour and Woolgar 1979, 91), architectural plans, etc., when they conduct participant or non-participant ethnography. Such direct forms of observation allow "naïve" observers (Latour 1987) to see what scientists discount as irrelevant details in their quest for scientific accuracy.

3. Constructing Relations as Research Objects: The Contribution of Paired Biographies

If the method of paired biographies involves comparing at least two pairs of cases, it does not mean that all studies based on multiple cases are examples of paired comparisons (or paired biographies). Thus, we need to better specify what the originality of paired biographies is.

3.1 Parallel vs. Paired Comparisons

Paired comparisons are sometimes simply equated with comparisons of two cases. Such confusion explains why quantitatively-oriented scholars deem paired comparisons a little better than single-case studies, but much less interesting than comparisons with large numbers of cases (Ragin 1987).

This view, however, is erroneous as it misses the difference between paired comparisons and what Theda Skocpol and Margaret Somers (1980, 176) call "parallel demonstration of theory" through comparison, or "parallel comparisons." Applied to the analysis of the spatial orderings of humans and objects, parallel comparisons, which involve the addition of multiple cases to illustrate a general law, can be found for instance in Richard Biernacki's (1995) masterful analysis of the spatial organization of labor sites in the early industrial age. In order to illustrate the general rule he uncovers – according to which spatial and social orderings and working bodies reinforce one another –, Biernacki cites two cases: market-oriented spaces of production (mostly found in British mills in the early nineteenth century), and hierarchy-oriented spaces of production (mostly found in German mills of the same era). Two cases are indeed better than one, and in each case, maps of concrete factory floors and partitioning walls demonstrate that spatial orderings reflect broader macro-cultural conceptions of social relations.

Still, the addition of a second case to a single-case study and the parallel drawn between the two cases fall short of constituting a paired comparison (Ragin 1987). Whereas the research object (for instance, concrete factory floor maps in the case of Biernacki) pre-exists the comparison itself in the case of parallel comparative demonstrations, it does not pre-exist the paired comparison: the research object (for instance, the tensions between imaginary spaces and concrete places) can only be constituted through the paired comparison itself. Thus, the "case" (or the research object) constituted by a paired comparison is already conceptual in nature: it is an object of a relational nature. In contrast, research objects constituted by single-case studies (especially those of an ethnographic kind) are often "given" by the empirical world to the researcher: one cannot stumble, for instance, on tensions between imaginary spaces and concrete places, just by walking in a specific site; in contrast, one can find the floor map of a factory in real life, without having constructed this spatial representation as an object of research.

The method of paired comparison is used here as a method of constructing a research object, and not, as many comparativist scholars in political sociology try to do (Moore 1965; Tilly 1986; McAdam, Tarrow and Tilly 2001), as a method of logical inference.[2] As Max Weber (2002 [1905]) observes, a paired comparison, which he uses systematically,[3] is a method of building ideal-types of relations (for instance, such relations as tensions or elective affinities). This relational (and conceptual) nature of the research object can explain why contemporary scholars understand Max Weber's method of paired comparison as a method of logical inference (Ragin 1987). Indeed, such relations (as tensions and elective affinities) could be rewritten (although with some important shifts) as "causal" relations: for instance, a tension between A (for instance, an imaginary space) and B (a concrete place) could be rewritten as a causal relation in the sense that B would result from A at the same time as it presents some features that contradict A (and therefore include feedback loops between B and A). Thus, contemporary scholars are tempted to use comparison as a means to test causal relations (Mahoney 2007). But here, I restrict the use of paired comparison to the construction of relations as research objects, and I will not tackle epistemological debates about causal inference.

3.2 Paired Biographies as a Sequence of Paired Comparisons

A paired biography, like other paired comparisons, is a method of constructing relations (like tensions) as a research object. But it is a specific type of paired comparison. The construction of the research object is done in a sequential

[2] Many scholars (Ragin 1987) who use the method of paired comparisons as a method of logical inference are influenced by John Stuart Mill and his famous methods of agreement and difference, which he proposed to test causal claims in an experimental setting – although they are aware of the criticism expressed by Durkheim (1982) against Mill's deterministic (e.g. non-probabilistic) conception of causality, which does not take into account the methodological problems of historical singularity and causal complexity in social scientific research.

[3] For instance, by comparing first, the relation (and tension) between Calvinist and Lutheran theologies and work ethics; then, by comparing the tension between sects and churches and work ethics within the world of Calvinist theology, etc.

manner through a series of paired comparisons: it is akin to the "process tracing" methods (Bunge 1997; Mahoney 2007), in which the process itself (here, the actualization of imaginary spaces into concrete places) is the outcome to be explained, e.g. the object of research. Paired biographies thus mix insights from both *comparative* and *genealogical* perspectives – or "before and after" (George and Bennett 2005, 81) analyses of the pair of cases, thus examined at different times.

Here, the method of paired biographies is applied to two types of spaces of science. The comparison is twofold: 1. It starts with a parallel comparison of two opposite spaces of science (the pre-WWII bucolic and machinic spaces of the Cavendish and the Rad Lab) in section 4; and, in section 5, 2. it traces how each model shaped a) the imaginary spaces of Oppenheimer and Lawrence, and b) the concrete places which resulted from the commission of two new laboratories (at Oak Ridge and Los Alamos, respectively) during the war. By comparing both cases, we can thus focus on the tensions between imaginary and real spaces.

4. The Contributions Offered by the Use of a Paired Comparison

The following section compares the spatial representations of science that served as models for both Oppenheimer and Lawrence when they were asked to build new research sites during the war: through a paired comparison, it constructs two ideal-types of imaginary spaces of science (one bucolic, the other machinic), which are best identified by placing one case next to the other.

4.1 The Bucolic World of the Cavendish Laboratory

Single-case studies provide rich descriptions of laboratory lives: they serve to illustrate how a spatial order reflects broader values and social boundaries, as in the case of Simon Shaffer's (1998) description of the Cavendish laboratory life, located in Cambridge (UK). Most of the discoveries that dismantled the Mendeleevian vision of the atom as the most elementary level of matter were done in the Cavendish Laboratory (Gordin 2004, 239). This is where Oppenheimer was first introduced to the experimental atmosphere of a physics laboratory and where he absorbed the Victorian values reflected in the imaginary and concrete organization of a scientific space (Bird and Sherwin 2006). Oppenheimer spent a very important year of assistantship at the Cavendish laboratory, under the chairmanship of Ernest Rutherford, and he associated the scientific values of equality among peers with this early experience.

The concrete spatial organization of the Cavendish laboratory reflected how the imaginary spaces of science were harmonized to fit with university values in the Victorian era. Until the end of the nineteenth century, in the U.K., the term "laboratory" was synonymous with terms like workshop, shop floor, mill, forge, loom (Forgan 1998, 199). The laboratory was thus an industrial space, deeply rooted in the industrial world, where learning methods consisted of visual imitation of manual practices. For instance, the proto-industrial workbench of the Curies' laboratory in Paris (see table 1) is often described as a shop-floor similar to the ones of women tailors working for the wool industry.

Table 1: Imaginary Spaces, Social Relations and Concrete places in Nuclear Science

Imaginary space	Concrete Spatial Organization	Modes of Authority	Laboratories
Proto-industrial	- Dispersed Workers - No boundary between house and shop floor - No gender boundary between living space and shop floor	- None -Horizontal contractual relations	- The Curies' workshop
Bucolic	- Concentrated Scientists - Strong Boundary between the industrial society and the laboratory - Non-compartmentalized Space within the Laboratory - Homo-Sociality	- Paternalistic inter-personal relations between scientists and the chair of the laboratory - One echelon of authority separating the professor from his students	- Cavendish Laboratory
Machinic	- Concentrated scientists along a division of labor aimed at mastering the understanding of the machine - Weak Boundary between the industrial society and the laboratory - Strong compartmentalization of Labor within the laboratory	- Strong boundary between managerial and technical functions - Multiplication of administrative echelons	- Berkeley Radiation Laboratory - Oak Ridge - Lawrence Livermore Laboratory
Frontier-style	- Concentrated Scientists - Strong Boundary between the industrial society and the laboratory - Mixed compartmentalization of the Interior Space of the factory (yes, for technicians, no, for scientists) - Inclusion of the living space within the perimeter of the space outside society	- Paternalistic inter-personal relations between scientists and the chair of the laboratory - Multiplication of administrative echelons	- Los Alamos

On the contrary, the term "university" was assimilated in the Victorian era to "academy," alma-mater, seminary, institute: terms that categorized a space outside society, where learning is conducted by purely formal and verbal exchanges (Forgan 1998, 199). Thus, as Simon Shaffer (1998, 149, 153) explains it,

> [t]he promoters of the new Cavendish (originally Devonshire) Laboratory established at Cambridge in the early 1870's had to explain how an expensive and challenging physics laboratory devoted to training in precise methods and research into physical standards could conceivably be reconciled with the values of the liberal academy and its mathematical elite [whose ideas] were best absorbed in studies and chapels, not at the workshop bench.

Still, the Victorian symbolic system was reflected in the spatial order and modes of authority found in the Cavendish laboratory (see table 1). Unlike the Curies' in Paris, the sponsors of the Cavendish laboratory shared the anti-modern attitude of fellows and professors in Oxbridge as well as their "bucolic epistemology that accompanies the view that social withdrawal is a precondition of access to universal truth" (Shaffer 1998, 153). Before they built the Cavendish laboratory in Cambridge, British gentlemen of science had successfully associated the laboratory with a different bucolic external environment: the gentleman's country house. In the 1860s, the Victorian country house was not only a place of leisure (what it has become since then), but also a place of innovation, particularly in the field of farming techniques. Having a private laboratory in one's country house was a political project against urbanization and industrialization, which was supported by Lord Rayleigh and other gentlemen farmers who sought to spread technological agricultural innovations across the British Empire (Shaffer 1998).[4] As a result, the Cavendish laboratory, modeled on Lord Rayleigh's private rural laboratory in his country house (Shaffer 1998, 167-8), was no longer seen as part of the industrial world, but on the contrary, was perceived to be part of the rural world outside urban society: it was the main outpost of this imperial model of political and economic development associated with Victorian imperialism.

To preserve the values of Victorian society, the internal space of the laboratory was partitioned in specific ways. The spatial organization of the country house of a gentleman of science had hermetically sealed boundaries between science and society (see table 1). Indeed, the presence of non-scientists (like spouses, daughters, nieces, maids, etc.) close to a laboratory meant that non-scientists who lived in the country house could threaten to disrupt the order of science at any time. To prevent that dreaded prospect, the Victorian country house became strongly segregated on the basis of gender: women could not access the private professional domains in the country house (composed of the laboratory and conservatory), and only had access to its public domains (the living and dining rooms); only men could access either of these private areas (Shaffer 1998; Findlen 1999).

[4] These private laboratories also produced important theoretical discoveries. It was in Lord Rayleigh's country house that properties of heavy gases like Argon were discovered in 1894, which later influenced technologies of isotopic separation based on differential atomic weights (used for instance at Oak Ridge).

Likewise, the internal spatial order of the university laboratory was modeled by strong spatial boundaries that followed gender lines. Like the country house laboratory before, the university laboratory of the Victorian era became embedded in a world of academic chapels, the “world without women” (Noble 1992). The strong equalitarian order that existed within the confines of the laboratory was sustained by the homo-sociality imposed upon the nuclear physics laboratory (as well as within the country house): such an equalitarian and collaborative order characteristic of the bucolic epistemology (where experimenters and theorists, teachers and students collaborated on an equal basis) was made possible by the social homogeneity among male students of the University, who mostly came from relatively rich families (like Oppenheimer, himself a student from Harvard).[5] In many ways, this was the world which Oppenheimer sought to reproduce, although in a very different context – wartime America –, when he was commissioned to create a laboratory devoted to the task of designing nuclear warheads, and which he chose to erect in the old all-boys school of Los Alamos.

4.2 The Machinic World of the “Rad Lab”

Whereas the bucolic model was created in reaction to industrial values, the machinic representation of the laboratory was fully embedded in the industrial world. The development of new machines by trans-disciplinary teams of researchers best characterizes the machinic model of the Radiation Laboratory (Rad Lab) that Ernest Lawrence built before the war. Compared to the prestigious Cavendish laboratory situated on the bucolic campus of Cambridge, Lawrence’s Rad Lab in the Bay Area looked like a garage lost in an urban suburb: the first 11-inch cyclotron that Lawrence had planned in 1929 to accelerate the potential of α-particles was housed in a disused civil engineering laboratory built close to the Berkeley campus (Heilbron, Seidel and Wheaton 1981).

Here, again, single case studies show how a symbolic system – one quite opposite to the imperial Victorian world of the Cavendish Laboratory – was reflected in the spatial organization of a laboratory (Heilbron, Seidel and Wheaton 1981). In contrast to Rutherford, who intended his laboratory to serve mostly research and teaching purposes, and who organized tables of experimenters in order to reflect this purpose, Lawrence situated his work at the intersection between research and the industrial development of machines used for practical as well as theoretical purposes. In the Far West of nuclear science, the

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[5] The association between the homo-sociality and the bucolic spatial imaginary is confirmed *a contrario* by the fact that urban and proto-industrial laboratories (like that of the Curies) were not spatially segregated on the basis of gender: the Radium Institute of Vienna also employed women as technicians (they counted scintillations of radiation) in a highly compartmentalized division of labor based on gender – a division of labor which scientists from the Cavendish laboratory found particularly “unscientific” (Stuewer 1985).

Rad Lab had patrons interested in the industrial or medical applications of Lawrence's research: the Rockefeller Foundation, Federal Telegraph, the Research Company, etc. Before the war, funding from industrial patrons was directed toward cancer research and the main purpose of the laboratory was to produce a machine big enough to interest these patrons (Heilbron, Seidel and Wheaton 1981:24). For instance, in 1936, the Chemical Foundation pledged his laboratory with $68,000 for a bigger medical cyclotron that would be used partly by his staff and partly by the Hospital of San Francisco (Heilbron, Seidel and Wheaton 1981). Thus, in Lawrence's Rad Lab, society had open access to his laboratory – in contrast to the closed bucolic laboratory.

Internally, the spatial organization of the Rad Lab was organized around the machine, whose construction and continuous experimentation was the main purpose of laboratory life (see table 1). It was not mapped on the model of a teaching laboratory (where experiments were done individually, and where instruments only served to illustrate a formal property of matter exposed by a professor to his students equal among themselves). Different groups of experts with different professional training (like engineers and scientists) freely circulated in the space in order to monitor and supervise the working of accelerators that were run for industrial patrons. The organization of Lawrence's laboratory thus pre-figured the one of research laboratories like CERN, where the maintenance and understanding of the functioning of the machine captivates most of the theoretical questioning (Knorr-Cetina 1999). The homo-sociality found in the laboratory (all were men) was here associated with the "frontier culture" of applied research in interwar (or contemporary) California (Heilbron, Seidel and Wheaton 1981): homo-sociality was not associated with any ideal of equality among men, or based on the principled exclusion of the women (identified with "society" in Victorian Britain).

The creation of the Rad Lab in the interwar period secured Lawrence's monopoly on the design of cyclotrons used for medical research: Lawrence's expertise was called on by Cornell, MIT, Princeton, Harvard, Chicago, Rochester and others to replicate the spatial organization for other physics laboratories. But with the war, a new application of Lawrence's research was found: Lawrence's expertise in isotopic separation appeared to be key for the construction of the two types of bombs: the plutonium bomb (from a trans-uranic element), which was based on the discovery by Segrè and Seaborg at the Radiation Laboratory, and the uranium bomb. During the war, Lawrence proposed to his new military patron, General Groves (the builder of the Pentagon building), to scale up the capacity of his 184-inch cyclotron assembled in Berkeley to separate the rare U^{235} from its abundant companion U^{238}. In March 1942, Lawrence planned that ninety-six 184-inch cyclotrons (called α-calutron) would take care of the job of separating enough U^{235} for a bomb (Heilbron, Seidel and Wheaton 1981, 34). As his laboratory in Berkeley was too small to welcome such an assemblage of machines, new facilities had to be constructed for the develop-

ment and manufacturing of enriched uranium and plutonium. In many ways, the war gave Lawrence the opportunity to scale up his Rad Lab and to further separate the space of the laboratory from the university context.
The next section studies the tensions that existed between the imaginary spaces dreamt up by Oppenheimer and Lawrence during the war and their concrete realizations at Oak Ridge and Los Alamos.

5. The Contributions Offered by the Use of Paired Biographies

The previous comparison not only sought to demonstrate that symbolic systems reflect themselves in the spatial representations of science in at least two cases (like a paired comparison), but it also highlighted the differences between these two specific symbolic systems and their associated spatial orders. The next step in the paired biographies method consists of comparing the processes by which the imaginary spaces of science formed before the war were materialized in concrete living places, and the tensions that emerged as a result of that process.

5.1 Los Alamos: Tensions between an Imaginary Space and Concrete Lives

Los Alamos originated from scientists' dream of preserving the pre-war organization of scientific labor associated with the bucolic order of the European teaching laboratory, even behind the high military fences erected to hide America's nuclear weapons project. There, the military sent all the European scientists in exile, who had worked with Enrico Fermi at the University of Chicago (where the first controlled nuclear reaction was performed in a reactor), so that they could design nuclear warheads under the chairmanship of Oppenheimer.

Scientists working in the U.S. prior to the decision to move to a hidden site to conduct the work of calculating the parameters of a nuclear explosion had strongly resented attempts by the military to create partitions and limit the circulation of information between themselves, and "one consequence of [their early struggles against the military management] was the establishment, over time, of a group of scientists who had struggled together to achieve a greater control over the workplace and over the disposition of the fruits of their labor" (Price 1995, 240). Responding to scientists' demands for greater control, General Groves, the military manager of security in the weapons project, asked Oppenheimer to set up a new laboratory where nuclear experimentation could be centralized and scientists freed from compartmentalization of information without compromising national security. Oppenheimer had in mind a campus-like setting, which would host small-scaled experimentations, but located outside of society, so as not to compromise national security. He chose to install his future laboratory in the picturesque all-boys school of Los Alamos, on a *Mesa*.

Oppenheimer's ideal for Los Alamos, which he soon named his "Shangri-La" (or his "magic mountain"), followed the bucolic and paternalistic epistemology that presided the construction of the Cavendish, where he had made his debut. Los Alamos would be the American equivalent of a Victorian country house, a rural setting for a private laboratory in charge of saving civilization from Barbary. Initially, Oppenheimer thought that Los Alamos would remain a small commune, with less than fifty top scientists carrying out the research necessary for developing the nuclear warhead designs (Hales 1997, 57). In many ways, the all-male scientists could fit in a small classroom. Oppenheimer realized this dream when he obtained from Groves permission for the scientists to gather for a weekly colloquium to publicly discuss the whole process of experimentation in a classroom. As Thorpe and Shapin (2000, 570-1) write:

> Gathering in one room, personnel from different Divisions [ordnance, theory, accelerator design, chemistry, etc.] and their Groups served to render visible the organization's intellectual and social coherence, to display Los Alamos to its inhabitants. […] In allowing for the Colloquia, it was understood that due to its geographical isolation, compartmentalization could be relaxed at Los Alamos. The laboratory would be one cell within the system, and its internal freedom would be made up for by the rigid policing of its external boundaries.

In order to turn his dream into reality, "Oppenheimer's plan was to attract his cadre by declaring high military necessity, by offering exciting scientific research in something resembling the pre-war utopia of the international scientific community, and by promising a living situation that was at least adequate" (Hales 1997, 75) for the families of the European scientists he would welcome in a place where European civilization could be recreated at the frontier (see table 1).

To some extent, Oppenheimer's bucolic imaginary space, far from raising obstacles for the military, was in elective affinity with its mode of reasoning and specific demands. As Peter Hales (1997, 44) writes:

> Oppenheimer's dream of isolation in nature fitted well with Groves' idea of separation of science from society, of separation of research from manufacturing. The military model for the programs followed the fortress philosophy: to consolidate all activities in a minimal space, and to surround that space with protective perimeter walls that could hide military activity. […] Original requirements for the new scientific sites had sought to duplicate the Pentagon Fortress in a natural local.

In that respect, Oppenheimer's early expression of keenness for militarization and isolation may have influenced Groves' decision to appoint him as director of the new laboratory (Thorpe and Shapin 2000, 565).

The comparison between Oppenheimer's imaginary space, whose socio-cultural roots I traced back to the Cavendish laboratory in the previous section, and the concrete reality of Los Alamos as a living place, makes manifest the tensions between imagined and real spaces. Indeed, General Groves immediately militarized the environment within which scientists would work in a way unforeseen by Oppenheimer (the Harvard-Cambridge-trained elite scientist who was more used to country club atmospheres than military barracks). Indeed, Oppenheimer's Shangri-La was "military-designed, military-built, as quickly and violently, and cheaply as possible" (Hales 1997, 74). For this reason, the "Shangri-La" quickly resembled an ever-expanding construction site, or a mining camp during California's Gold Rush.

The comparison between the imaginary and real spaces of science in Los Alamos also highlights the conflicts and tensions around the military spatial ordering of bodies, and the unexpected result that emerged from the move of whole families of Europeans scientists to a Frontier town. Like the Cavendish laboratory, Los Alamos was characterized at its inception by a strong gendered division of laboratory life between the private and public spaces. At the beginning, Oppenheimer planned that Los Alamos would become a country club of gentlemen, where he would take care of the lives of his the scientists-guests and their wives, nicely housed and served by American Indian maids (Thorpe and Shapin 2000, 575) – as Los Alamos was located on an American Indian reserve. For security reasons, Groves insisted that the laboratory of Los Alamos be hidden by a series of concentric fenced areas isolating the "Technical Area" (the laboratory) from the public life in the camp. The laboratory was only accessible to scientists with security clearances (provided by the military) and to the male engineers of the Army Corps of Engineers and its Special Engineer Detachment (SED). As a result of this military environment, the laboratory space was at first mostly private and male-dominated, the wives of scientists being mostly visible in the public spaces of the camp.

However, during the war, the gendered division of the camp was highly resented by the wives of the scientists who lived outside the space where their husbands worked, and could not access its private parts. For instance, the wife of Enrico Fermi (1954) explains how scientists' wives, who were used to collaborating with their husbands in pre-war continental Europe (as on the Curies' shop floor) united to struggle against such gendered compartmentalization of their living spaces. This situation created so much frustration that at one point, the doors of the "Technical Area" opened for women, even if only to work as "computers," in instrumental and repetitive tasks (Hales 1997). The introduction of women computers, technicians and military engineers into the laboratory transformed the original idea that Oppenheimer had for Los Alamos. It was no longer the planned teaching laboratory where scientists would work with paper and pencils in classrooms, but a research laboratory where specialized groups of experts put their work to the service of a common goal.

As a result of these tensions between imagined and concrete spaces, the end of the war led to the immediate departure of the scientists and families from Los Alamos. European scientists and their families would have stayed in a nice country club atmosphere, but not in a militarized bunker with high fences that separated technical areas from a frontier town. After the war, like many of the other scientists, Oppenheimer himself did not stay at Los Alamos (Bird and Sherwin 2007). He moved to an East Coast campus, accepting a position at the Princeton Institute for Advanced Studies, not too far away from Washington, where he became the first advisor to the newly created Atomic Energy Commission. At Princeton, he joined a department peopled of top scientists like von Neumann, Einstein and Wheeler. There, he enjoyed again the warm atmosphere of a country club: the Princeton Institute, well-known for its monastic life-style, even isolated from the campus of Princeton University itself, already isolated from the urban industrial life of East Coast cities, was organized around a community of peers considered to be leaders in their discipline, and the absence of compartmentalized labor.

The divorce between the promised space and the concrete place that was shaped by the military according to military logics continued to shape the living choices of nuclear scientists. When research on thermonuclear weapons (based on the fusion rather than the fission of atoms), again caught the attention of scientists and policymakers in the early Fifties, military men and policymakers failed to attract scientists back to Los Alamos, despite the fact that all research on nuclear weapons designs was supposed to be located there. Research on the H-bomb actually came to the Princeton Institute of Advanced Studies as "Wheeler received support from Oppenheimer" (Galison and Bernstein 1989, 320), but failed to convince the members of the Institute to come back to Los Alamos to conduct research on the H-bomb. As Wheeler said, "seeing that the men [from the Institute] won't come to the work, I have moved the work to the men" (cited in Galison and Bernstein 1989, 321) at the Institute of Advanced Studies. In the initial phase of the H-Bomb project, the bucolic life style of the Institute fitted perfectly with the task. Princeton had central assets to lead research on the H-bomb from the Institute: projects in astrophysics, hydrodynamics and nuclear theory, but also the MANIAC computer installed at the Institute (Galison and Bernstein 1989, 320). The MANIAC computer allowed the size of the laboratory to remain small, as Oppenheimer had first wanted Los Alamos to be (with only 50 scientists), and the mechanical computer made it unnecessary for the wives of scientists to work on simple calculations as "computers," as they had done in Los Alamos (Mahoney 2001). Scientists did not need to live in a frontier town like Los Alamos where the lives and labor of human computers and technical assistants were highly compartmentalized and controlled.

5.2 Oak Ridge: Unexpected Affinity between Imaginary and Real Spaces of Science

If some aspects of the bucolic imaginary space initially proposed for Los Alamos reflected the affinity between scientists' aspirations and a military environment, they were soon destroyed by the military realities. In contrast, the machinic imaginary space of Lawrence's Radiation Laboratory found their full expression when Lawrence moved with his staff to improve uranium enrichment techniques at Oak Ridge.

The involvement of Lawrence's staff at Oak Ridge was not planned by either scientists or the military at the inception of the process. Unlike Los Alamos, Oak Ridge did not result from a planned effort to move scientists outside of university campuses for national security reasons. According to the planned division of labor (where the military and its private sub-contractors were responsible for the manufacturing part; and the scientists were responsible for the R&D), scientists like Lawrence and his staff at Berkeley should not have been involved in the manufacturing sites like Oak Ridge (Hales 1997, 34). General Groves moved the manufacturing site from Argonne to Oak Ridge and Hanford after he subcontracted the activity to DuPont.

Still, in Oak Ridge, research and development quickly co-existed with manufacturing, as new problems emerged with the incredibly quick scaling-up of processes first tested in Lawrence's Rad Lab on a very small scale. As Newman (1951, 1319) notices, "[t]he decision in the winter 1942-3 to invest $350 millions in the extraction and purification [of uranium and plutonium] facilities at Hanford and Oak Ridge was based on research findings [at Berkeley] made with only half a milligram of plutonium." Of course, when scales change so drastically and so quickly, a lot of contingencies appear. For instance, in August 1943, the first racetrack in the α-calutrons operating at Oak Ridge immediately collapsed due to leakage in the vacuum chambers that were supposed to receive the U^{235}. Finding out what happened in the complex machine created by Lawrence became the main center of attention of his staff. As a result, a big part of Lawrence's staff stayed in Berkeley to train operators, but another large part including Lawrence himself moved back and forth between Berkeley and Oak Ridge to fix problems and understand how his machines worked when assembled in large numbers.

The industrial environment of Oak Ridge reinforced the machinic culture among Lawrence's staff and accelerated the installation of scientists with a non-bucolic culture at Oak Ridge. Before the war, patron/client relations characterized Lawrence's relations with the industrial world. But the war transformed his relations with industrial corporations into one of competition: in Oak Ridge, the accelerators of particles that Lawrence developed were in direct competition with industrial processes of uranium separation developed at the same time by DuPont. Indeed, the military had decided to develop three methods of separation of uranium to maximize the likelihood of success, costing $800 millions in total: thermal diffusion, which used tremendous heat to separate the two isotopes; Lawrence's method of electromagnetic separation, which whirled uranium atoms in large semi-circular α-calutrons; and gaseous diffusion, which made use of Lord Rayleigh's discovery of the atomic weight of heavy gases. This latter process, taking place in the largest industrial plant in the world at the time (under a 60-acre roof), quickly provided the best results. As a result, in the winter of 1943, the U.S. government threatened to shut down the plant where Lawrence's process was tested (Seidel 1983). To overcome the crisis and to win over his industrial competitors, Lawrence's staff constantly moved back and forth from Berkeley to Oak Ridge to perfect the assemblage of machines. As a result, Lawrence's credibility was firmly established after he invented another type of accelerator – the β-calutrons –, which added a second process of electromagnetic separation after the first racetracks had purified natural uranium. The assemblage of α-calutrons and β-calutrons gave good enough results (Heilbron, Seidel and Wheaton 1981), so that General Groves decided to treat all the purified uranium with Lawrence's β-calutrons at the end of each process of separation.

The industrial environment in which Lawrence's staff installed his R&D laboratory at Oak Ridge also strengthened the compartmentalized character of the living and working places of nuclear science. In Oak Ridge, internal compartmentalization touched scientists and technicians at a much higher level than in Los Alamos or in Berkeley because of the industrial organization of labor. At the end of the war, 50,000 people were working in the three industrial sites of uranium separation, and most of them where hired without knowing what their work was supposed to produce (Hales 1997). In Oak Ridge, the execution of processes was done by many operators, mostly women, who did not have to understand the purpose of their activity. Pictures taken at Oak Ridge just after the war contrast the dominant attitudes between Lawrence and his staff: Lawrence casually sitting on the machine built by his staff, and the women operators working in line in front of the machines that dominated their moves (Hales 1997). Furthermore, the site itself was declared a military exclusionary zone, which made even local and state laws invalid, a decision that the Governor of Tennessee (a Southern state) stopped objecting to after he obtained promises for better infrastructure (roads, railways, housing, education) from federal welfare agencies (like the Federal Housing Administration, the Tennessee Valley Authority, the Federal Works Administration, etc.). Thus, military city planning based on gender and racial segregation in Oak Ridge redoubled the segregation along gender and racial lines that one found at work (Hales 1997).

The elective affinity between the machinic culture found in Lawrence's laboratory's spatial orders and the military way of thinking was made manifest to all during the war, and this realization had important effects on Lawrence's career and future ability to create new laboratory spaces after the war. Indeed, General Groves felt much more affinity with Lawrence than with Oppenheimer (Seidel 1983). Whereas Oppenheimer and other scientists at Los Alamos sent numerous complaints to General Groves about housing and compartmentalization of labor, Lawrence successfully played the race for technical innovation without complaining about the military management of his staff, including his scientific staff. In fact, Lawrence was one of the few scientists supporting the May-Johnson bill (proposed by the Department of War), which planned to leave the control of post-war nuclear science and industry to military management (Newman 1951). Thus, after the war, it was not a surprise that the Rad Lab in Berkeley and Lawrence's laboratory at Oak Ridge were integrated into a common network of National Laboratories (Westwick 2003), which aimed at anchoring the industrial and military worlds in the world of laboratories. As Heilbron, Seidel and Wheaton (1981, 62-3) write: "after the war, Lawrence did not fully demobilize his laboratory: he continued to push the calutron process, the efficiency of which he promised to increase tenfold," and when "Lawrence and others decided to put the laboratory behind Edward Teller's program for thermonuclear weapon" in the early 1950s, they lobbied Washington to get funding for the development of a neutron-producing reactor. When Lawrence obtained a $100 million linear accelerator, releasing neutrons by accelerating deuterium at high energies, the military commissioned him for the creation of a second laboratory in the Bay area, close to his Berkeley site. Emblematically, Lawrence located the new laboratory in the old naval base of Livermore, where he did what he had done in Berkeley twenty years before and in Oak Ridge ten years before.

6. Conclusion

The method of paired biographies applied to study working spaces highlights the existence of both tensions and elective affinities between imaginary spaces of science envisioned by scientists and concrete scientific places (themselves located in a broader environment) whose construction involves the help of many other actors (here, mostly military personnel). The first comparison serves to highlight the main differences between two symbolic systems of social classification, which are reflected in the spatial representations of science (Cavendish and Rad Lab); the second comparison serves to construct the tensions (and affinities) between imaginary and concrete spaces of science as an object of this research. The other comparison between Lawrence's Rad Lab and the site that he (eventually) came to design at Oak Ridge (although initially he was not asked to do it) serves to show the (unexpected) elective affinities between Lawrence's imaginary space of science and the concrete realities of military-industrial project that appeared during the war.

The two-step comparative approach exemplified by the method of paired biographies serves to avoid a common mistake which consists in essentializing certain features of places that ethnographers visit after the period of their construction. For instance, after the war, a “naïve” visitor in Los Alamos and Oak Ridge might have concluded that both sites reflected similar values, to the extent that they both made manifest the militarization of big science (Rhodes 1986) in Frontier Towns. But in both cases (Los Alamos and Oak Ridge), the concrete places of science did not reflect the initial pre-conceptions of the scientists who actively participated in shaping these sites: in the first case, the military and the families of scientists subverted the clean bucolic order envisioned by Oppenheimer for Los Alamos; in the second case, industrial contingencies explain why a site that was not initially conceived for scientists (Oak Ridge) became a scientific worksite upon which the machinic order of science was grafted. Thus, by conducting these paired comparisons in a sequential manner, we improve our understanding of the contingencies that led toward the unexpected convergence between the spatial ordering of (gendered) bodies and machines in both places (as illustrated by the fact that both Oak Ridge and Los Alamos were incorporated into the same network of National Labs).

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