CHAPTER 5

"Preservation of the Laboratory Is Not a Mission." Gradual Organizational Renewal in National Laboratories in Germany and the USA

Olof Hallonsten and Thomas Heinze

5.1 Introduction

The scientific utilization of very large and costly infrastructure—often referred to as "Big Science"—originated with the rise of competition between superpowers at the end of World War II and the tremendous belief in (and fear of) nuclear energy that fed into it. The demonstration of the force of nuclear energy over Hiroshima on August 6, 1945, was essentially the motivation for the initial creation of Big Science laboratories. Generously sponsored national programs for science and technology fostered the development of weapons technologies and civilian use of nuclear

O. Hallonsten
Lund University, Lund, Sweden

T. Heinze (✉)
University of Wuppertal, Wuppertal, Germany

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energy, foremost in the USA, the Soviet Union, Great Britain, and France. The construction of ever-larger particle accelerators to discover new sub-nuclear particles and forces became a manifest feature of the postwar mobilization of science and technology for the benefit of society, the economy, and national security.[1]

The Big Science facilities that were created during this era were essentially mission oriented, and their rise to preeminence in national R&D systems was guided by the unarticulated principle that the accelerators would no longer be useful once the atom's inner structure was fully mapped. To some extent, this premise was correct, since most of the accelerators that were built to search for elementary particles have been shut down. Nowadays, global experimental particle physics (PP) research is concentrated at CERN (Conseil Européen pour la Recherche Nucléaire, the European Organization for Nuclear Research) in Geneva, which hosts the collaborative work of the countries of Europe as well as China, Japan, Russia, and the USA. But interestingly, even following the accomplishment of missions and subsequent desertion of accelerators, the Big Science organizations hosting them remain in place, with very few exceptions, and their shares of national R&D budgets remain as large as ever.

In this chapter, we analyze this seemingly paradoxical state of affairs and explain the organizational processes of change and adaptation that have led to the renewal and survival of Big Science laboratories beyond the completion of their original research missions. In this way, this chapter contributes to what the editors of this volume call "investments in exploration" via adaptation and internal change of existing research organizations. We focus on two systems of national laboratories: that in Germany and that in the USA.[2] Each system functions within its national R&D system to orchestrate the construction and operation of costly research infrastructure and to conduct large-scale scientific and technological programs. Furthermore, both the German and US systems have continued these operations despite considerable changes in the technical nature and areas of use of their infrastructures, and in the contents of their R&D programs, due to the altered demands and expectations from a wide range of scientific fields and from policy makers and society. Important to note is that although Germany and the USA differ fundamentally in the structures of their respective R&D systems, not to mention their (twentieth century) histories and thus their political and institutional foundations for publicly sponsored R&D, the two systems of national laboratories under study are quite alike. As the chapter will show, not least do the processes of adaptation, renewal, and change in the two systems in the past several decades show remarkable similarities. At first sight, therefore, the differences may give the impression of an imbalanced historical comparison of renewal of Big Science in one postwar military and economic superpower and one war-torn European country, but since the two systems under study have far-reaching similarities, the specific combination of Germany and the USA as empirical foci of the analysis adds strength and generalizability to the conclusions.

We examine case studies of two laboratories: DESY (Deutsches Elektronen-Synchrotron, German Electron Synchrotron) in Hamburg, and SLAC (SLAC National Accelerator Laboratory, formerly Stanford Linear Accelerator Center) in Menlo Park, California. These laboratory histories suggest typical patterns according to which laboratories can renew themselves in order to adapt to change. These two laboratories have, in the course of their approximately 50-year histories, undergone gradual but cumulative change with respect to their research missions, from being the flagship PP labs of their respective countries and thus charged with a single mission, to a situation today where they operate no PP machines but rather state-of-the-art photon science (PS) facilities for users from a wide range of the natural sciences, mostly within materials science and the life sciences (broadly defined) but also several other areas. To some extent, these transformations of DESY and SLAC from PP to PS mirror a global development whereby PP has gradually stood back as the main area of utility of large accelerator complexes, and whereby the use of synchrotron radiation (SR) has partly taken its place in contemporary Big Science. Given their sizes, DESY and SLAC have been major players in this global transformation and in some instances pioneered the use of accelerators for SR,[3] but they have not been the lone drivers of the change. Several other interesting studies of the explosive growth of SR as an experimental technique for a wide range of natural sciences exist that use other cases and tell partly different stories.[4] As a dual case study, the chapter therefore has auxiliary relevance as a component piece in the study of how SR came to be a prominent feature of contemporary experimental natural science. But importantly, the focus of the chapter does not lie there, but on the topic of scientific and organizational renewal of national laboratories, and the aims of the chapter are to analyze such renewal in a more general to draw broader conclusions. As mentioned, the complementarity offered by the differences between the two national laboratory systems wherein the cases under study are located adds to the generalizability of the analysis and the conclusions—theoretically, methodologically, and empirically.

Building on prior work, we distinguish four different processes of renewal, and discuss how they interact at the micro (laboratory components) and meso (laboratory) levels and what this means at the macro (research system) level. From this analysis, we infer that the multidimensional and multilevel renewal of national laboratory systems has been instrumental to their survival. The multidimensional renewal processes is key to understanding what the editors of this volume call "investments in exploration." The two cases of DESY and SLAC show how Big Science laboratories were restructured in order to address new scientific problems and challenges. That these investments in SR research/PS have already born fruit, is illustrated by several Nobel Prizes in Chemistry since the late 1990s that have built directly on experimental work at labs like DESY and SLAC, including John Walker (1997), Roderick MacKinnon (2003), Roger Kornberg (2006), Ada Yonath, Thomas Steitz and Venkatraman Ramakrishnan (2009), and Robert Lefkowitz and Brian Kobilka (2012).

We begin by briefly outlining the histories of the two national laboratory systems and how they have grown and transformed since their inception in the late 1940s (USA) and the mid-1950s (Germany). Thereafter, we present the conceptual framework and use it to analyze changes at different levels, considering our knowledge about both the micro and meso levels. The two selected cases enable us to suggest patterns of renewal at the level of the construction and operation of large scientific infrastructure, as well as the scientific activities inside the laboratories. We conclude by focusing on the macro level and the general question of renewal and how laboratories and the systems they comprise have survived despite fundamentally altered political, economic, and military framework conditions.[5]

5.2 Systems of National Laboratories in the USA and Germany

The basic purpose of the present analysis is to determine why none of the national laboratories in Germany and the USA have ever been closed, despite considerable changes or even decline and expiration of their original missions. Tables 5.1 and 5.2 list the laboratories of the two systems, along with some basic information.

Ten US National Laboratories are defined as laboratories under the stewardship and main sponsorship of the US Department of Energy's

(DOE) Office of Science.[6] Each is governmentally owned and contractor operated (a legal status commonly called GOCO). Constituting a de facto fourth regular sector of R&D performers in the USA—besides industry, academia, and the government itself—the US National Laboratories are nonprofit but may assume whatever organizational form the contractor finds suitable, including firm, university department, trust, fund, association, or subsidiary and branch of any of these.[7] In addition to these ten laboratories under the Office of Science, there are seven other National Laboratories with responsibility for weapons programs and other classified governmental R&D (including, but not limited to, nuclear arms), which are overseen by other branches of the DOE and, in some cases, the Department of Defense. These seven laboratories are excluded from the analysis since their activities and organizations are classified.

The German Helmholtz Research Centers are wholly civilian R&D centers that operate as limited companies or public and private foundations, and that are all under the umbrella organization the Helmholtz Association. Similar to the situation in the USA, the German Federal Government assigns the Hemholtz centers a unique role in the national R&D system—namely, the construction, maintenance, and operation of large scientific infrastructure.[8] In contrast to the situation in the USA, the Helmholtz Association is a separate legal entity and constitutes an umbrella organization.[9]

Table 5.1 The United States National Laboratories under the DOE Office of Science

Name	*Location*	*Founded*
Lawrence Berkeley National Laboratory (LBNL)	Berkeley, CA	1931/1947[a]
Oak Ridge National Laboratory (ORNL)	Oak Ridge, TN	1943/1947[a]
Argonne National Laboratory (ANL)	Argonne, IL	1947
Ames Laboratory (AL)	Ames, IA	1947
Brookhaven National Laboratory (BNL)	Upton, Long Island, NY	1947
Princeton Plasma Physics Laboratory (PPPL)	Princeton, NJ	1953
SLAC National Accelerator Laboratory (SLAC)	Menlo Park, CA	1962
Pacific Northwest National Laboratory (PNNL)	Richland, WA	1965
Fermi National Accelerator Laboratory (FNAL)	Batavia, IL	1967
Thomas Jefferson National Accelerator Facility (TJNAL)	Newport News, VA	1984

[a]These labs were founded in other shapes before (LNBL) and during (ORNL) World War II, and were made National Laboratories in 1947.

Table 5.2 The German Helmholtz Research Centers

Name	*Location*	*Founded*
Center for Materials and Coastal Research (GKSS)	Geesthacht/Teltow	1956
Forschungszentrum Jülich (FZJ)	Jülich	1956
Karlsruhe Institute of Technology (KIT)	Karlsruhe	1956/2009[a]
Deutsches Elektronen-Synchrotron (DESY)	Hamburg/Zeuthen	1959
Max Planck Institute for Plasma Physics (IPP)	Garching/Greifswald	1960
German Research Center for Environmental Health (KMGU)	München	1964
German Aerospace Center (DLR)	Köln	1969
GSI Center for Heavy Ion Research (GSI)	Darmstadt	1969
Center for Infection Research (HZI)	Braunschweig	1976
German Cancer Research Center (DKFZ)	Heidelberg	1976
Alfred Wegener Institute for Polar and Marine Research (AWI)	Bremerhaven/Potsdam/Sylt	1980
Center for Environmental Research (UFZ)	Leipzig/Halle/Magdeburg	1991
German Research Center for Geosciences (GFZ)	Potsdam	1992
Max Delbrück Center for Molecular Medicine (MDC)	Berlin-Buch	1992
German Center for Neurodegenerative Diseases (DZNE)	Bonn/Tübingen/Dresden	2009
Helmholtz Center Berlin for Materials and Energy (HZB)	Berlin	1957/2009[b]
Helmholtz Center Dresden-Rossendorf (HZDR)	Dresden	2011[c]

[a]The Forschungszentrum Karlsruhe (FZK), founded in 1956, merged with University of Karlsruhe in 2009 and formed the KIT.

[b]HZB is a merged entity of the former Hahn-Meitner Institute (founded in 1957) and the former Berlin Electron Storage Ring Company for Synchrotron Radiation (formerly a member of the Leibniz Association).

[b]HZDR is not a new entity, but was transferred from the Leibniz Association to the Helmholtz Association.

The majority of funding for the US National Laboratories comes from the DOE in the form of federal first-stream institutional core funding. Similarly, the Helmholtz centers have their core funding in institutional grants from the German Federal Government (90%) and from the respective Länder States wherein the labs reside (10%). However, institutional core funding is presently declining in both systems, which reflects both limitations of the financial capacities of the respective federal governments, and a political strategy in both countries to shift toward allocation of funding via soft money.[10]

Since the 1950s, the US National Laboratories have gone through three major growth-decline budget cycles, which have largely not correlated with numerical variations in the laboratory system. While the first budget expansion was directly connected to a steep growth in the total number of laboratories in the 1950s and the 1960s, the real terms budget decline of the 1970s occurred with no corresponding change in laboratory number. In contrast, the substantial budget increase in the 1980s coincided with only one newly founded lab. Budget austerity in the 1990s caused no laboratory shutdowns, and a return to budget growth in the early 2000s was not associated with any new laboratories. In comparison, the Helmholtz centers have experienced two similar major growth-decline budget cycles, which were also disconnected from the variation in total number of research centers. Substantial budget growth in the 1960s and 1970s was channeled into those laboratories founded in the 1950s. Furthermore, although the budget stagnated in the 1990s and 2000s, the number of laboratories increased.[11]

The first two US National Laboratories were founded on the remnants of the Manhattan Project, as a means to harness the weapons R&D resources for similar work in the postwar era, and expand them to other services for the military, the economy, and society at large.[12] Simultaneously, in 1947, three additional laboratories were created in other regions of the USA. The expansion period of this system of US National Laboratories lasted until the end of the 1960s, with particular growth occurring after the escalation of the Cold War in the mid- to late 1950s. By 1967, nine of the present ten civilian national laboratories had been established. In 1974, the steward agency of the labs, the Atomic Energy Commission (AEC), was replaced by the Energy Research and Development Administration (ERDA) as part of an attempt to better coordinate federal energy policy in the wake of the oil crisis.[13] This reform was also rooted in concerns that grew throughout the 1960s regarding the steeply increasing expenditure on National Laboratories, which were combined with a waning belief in the linear model of technological innovation, strong criticism toward the "military-industrial complex," and clear shifts in political priorities.[14]

The economic downturn in the 1970s caused some decline in spending in the US National Laboratories system, but this tendency again turned into growth with the renewed superpower competition and reinvigorated weapons programs spending in the 1980s. These changes also brought federal science spending in general to new heights, and launched several new projects. The previous economic downturn left lingering concerns over the role of Federal Laboratories in the national R&D system, which led to a series of legislative reforms in the 1980s, adding technology transfer and innovation to the laboratory missions.[15]

This trend continued throughout the 1990s. As the Cold War ended, the value of the spending on the National Laboratories came under severe criticism, leading to a rather dramatic downturn in laboratory funding. The Superconducting Super Collider project was closed before completion in 1993;[16] however, this case of termination has remained exceptional and did not create a precedent for any other US National Laboratory, despite their reduced budgets. In the 2000s, spending growth resumed and several major new projects were launched within the system, including the Spallation Neutron Source at Oak Ridge and the Linac Coherent Light Source (LCLS) at SLAC.

The first German national laboratories were founded in 1956, shortly after the lifting of the allied ban on nuclear research in the Federal Republic of Germany. A reactivation of the German research capabilities in nuclear physics had been promoted for several years by a strong lobbying group that stood ready to realize their plans once the ban was lifted. Between 1956 and 1959, no less than five large laboratories in the area of nuclear/PP were founded, and a designated Ministry for Atomic Matters was created. These efforts were accompanied by continuous reference to the emerging system of National Laboratories in the USA.[17] The following 15-year period witnessed significant expansions of the number of laboratories and the overall budget. Between 1964 and 1976, six new laboratories were founded and the overall inflation-adjusted budget almost tripled. These expansions included great diversification of the laboratories' research portfolios, from nuclear/PP to space and flight research, information technology, medicine, and biotechnology, among other areas.

Toward the end of the 1970s and into the 1980s, governmental authorities branded several nuclear research centers as having outlived their original purposes, and forced these centers to cut expenditures and personnel. As part of the same reevaluation of priorities, other laboratories were instructed to engage more actively in technology transfer and to diversify their activities for the benefit of society. Except for a short downturn in the early 1980s, the overall budget grew between 1977 and 1989. This growth included the founding of a new laboratory in polar and marine research (1983) and the launch of an additional funding stream toward the laboratories, which took the form of project funding schemes in thematically oriented areas and with specific funding opportunities for technology transfer activities.[18]

As a result of the 1990 German reunification, three new laboratories were founded in the early 1990s. In contrast to in the USA, the German system enjoyed institutional stability and even strength in the 1990s, largely due to the copying and extension of the governance structures of the formerly West German research organizations into the eastern part of the country. However, this expansion was not matched by any substantial funding increases, meaning that the new laboratories in the eastern part of Germany came at the expense of budget cuts suffered by the preexisting Western laboratories. In 2001, the Helmholtz Association was established as an umbrella organization within which all laboratories compete for individual shares of the overall five-year research budgets. While the German Federal Government remains the main sponsor, this reform made it less involved in agenda setting for the Helmholtz Centers and it has left most policy and decision making to the Helmholtz Association and its external peer reviewers.[19]

The key lesson drawn from these brief historical sketches is that the two laboratory systems have remained persistent and stable entities in their national public research systems, despite budgetary expansions and contractions and a series of substantial changes in their societal environments. This institutional stability sharply contrasts with the dramatic research portfolio changes that have occurred in all of these laboratories. At their founding in 1947, the original US laboratories had nuclear energy or nuclear energy-related R&D as original research mission. While the scope of this mission could be stretched quite far into several other areas of research, more or less at the discretion of lab directors, it was rather narrowly focused on nuclear energy in comparison with today's vast assortment of missions as regulated by the DOE and the US Congress: as chemical and molecular science, biological systems science, climate change science, applied materials science and engineering, and chemical engineering.[20] The original German laboratories were founded in the mid- to late 1950s as single-mission nuclear and PP centers, but today their research portfolios include climate change science, applied materials science and engineering, computer science, biotechnology, PS, astroparticle physics (APP), and chemical and molecular science.[21]

Given this vast expansion and change of the batteries of missions in the two systems of laboratories over more than 50 years, a central question is how such change has been accomplished on meso and micro levels, that is, on the level of laboratories and on the sublevel of research programs and large-scale infrastructure projects within the laboratories. To facilitate the analysis of change on these levels a conceptual framework will be introduced in Sect. 5.3 and put to use in the case analyses in Sect. 5.4.

5.3 Processes of Gradual Organizational Renewal

Scholars in the study of institutional change have successfully developed two diametrically opposed versions of the concept of path dependence. On one hand, institutions can be sustained and reinforced through time by increasing returns and positive feedback processes. On the other hand, institutions can be formed at critical junctures provoked by radical change and the complementary identification of long periods of continuity and stability.[22] Recent advances in institutional theory complement these views, and argue that the processes and results of change should be considered variables in a theoretical framework that enables analysis of the gradual but cumulative adaptation of institutions.[23] The concept of incremental yet transformative change can also be applied to organizational change, and thus to the national laboratory systems of the USA and Germany, since they both seem to have evolved along gradual paths of organizational change rather than through events of radical system shocks.[24]

The fact that no laboratory in either of these two systems has ever been closed is testament to their institutional (macro level) persistence, as well as an indication that in general terms, the sponsorship relationships between the federal states and the laboratory systems have remained intact over time. Additionally, it appears that the overall major function of the laboratory systems is relatively stable within their respective national R&D systems. System (macro) level persistence might be viewed as an aggregation of continuity at the organizational (meso) level, meaning that the two national systems are stable because their constituent parts (the individual laboratories) are stable entities. This is true insofar as the laboratories are intact as organizational entities. However, as will be shown below, there exists considerable evidence of profound changes in the laboratory components (micro level), including the technical infrastructure, research fields, and organizational units. Therefore, it appears that gradual changes at the micro level have provided both the laboratories (meso level) and the two national systems (macro level) with the capacity to successfully adapt and survive over several decades.

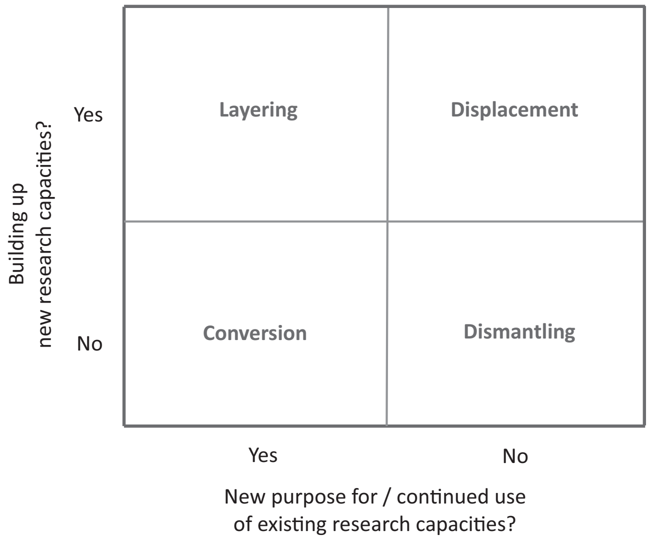

Fig. 5.1 Processes of gradual institutional change within research systems and research organizations

This conceptual scheme is designed such that the same analytical categories are applicable on all three levels (macro, meso, and micro). Figure 5.1 shows a cross-tabulation; the vertical axis indicates whether new research capacities are built up (including new technical infrastructure, the recruitment of scientists representing new research fields, or new organizational units), while the horizontal axis indicates whether existing research capacities continue to be used (including use for new purposes). The processes of gradual change in Fig. 5.1 are as follows. *Layering* is a process by which new arrangements are added on top of preexisting structures, thus enabling the accommodation of new elements without excessively compromising the logic of the preexisting structure. In contrast, *conversion* refers to when capacities for one set of goals are redirected to other ends, in a process that neither adds new capacities nor terminates the existing capacities. On the other hand, *displacement* means that research capacities are discontinued, as new ones are added in their place. Finally, *dismantling* simply means that research capacities—including technical infrastructures or research units—cease to be used without being replaced by new capacities.[25]

On the level of national laboratory systems, one straightforward process of gradual change is macro-level layering by the addition of new laboratories to the system. With few exceptions, this process occurs during concentrated time periods of expansion and diversification. Macro-level layering took place in the USA foremost in the 1950s and 1960s, and in Germany in the 1960s–1970s and during a short period in the early 1990s following German reunification. Outside of these periods, the two national systems have not grown numerically but only in terms of increasing budgets, which means that such budget growth has been absorbed by existing laboratories, thus indicating some form of micro-level layering (the addition of new research capacities), micro-level displacement (the substitution of existing research capacities for new, more expensive ones), or micro-level conversion (the redirection of existing capacities toward new, more expensive purposes and research fields), or any combination of these.

Micro-level changes can lead to meso-level transformations of whole laboratories. As will be shown below, DESY and SLAC are particularly interesting examples of how a series of intra-organizational (micro-level) changes can lead to full-scale organizational (meso-level) renewal. However, not all micro-level changes will necessarily cumulate into full-scale renewal at the laboratory level. The brief historical outlines in the previous section suggest that each federal government reevaluated their research policies and funding priorities in the wake of the economic downturn in the 1970s, and again at the end of the Cold War, which forced several laboratories to reconsider their missions and their planning.[26] However, while many laboratories initiated new projects and activities under the stewardship of their funders, these micro-level changes did not always lead to full-scale meso-level renewal with new dedicated research missions. Rather, several laboratories, especially when their budgets expanded, built on their multimission legacies and incorporated additional programs and projects into their portfolios without significantly altering their identities or mission statements but rather just increasing their diversification as an element in their pursued preservation of organizational status quo.[27] Therefore, while macro-level change is evident in the two systems, it is not simply linearly traceable back to micro-level changes—the accumulation of gradual changes inside labs into higher-level transformations is neither automatic nor straightforward.

Renewal can be examined in terms of three different dimensions: technical infrastructure, scientific fields, and organizational units. Change processes are typically multidimensional, multilevel, and multitemporal in the sense that a change process in one dimension, on one level, or on one timescale can translate to another change on another dimension, level, or timescale. For example, the layering of a new scientific activity with one piece of technical infrastructure on top of an existing one might eventually result in the new scientific activity taking over the piece of infrastructure. In this case, it would be possible to identify the layering of the new research field on top of the existing fields, then the dismantling of existing research areas, and finally the displacement of the original research field's use of the infrastructure by the new research field. Simultaneously, the components of the infrastructure itself might be layered, dismantled, replaced, or converted at various points in time and as part of the overall transformation.

In the next section, we will use the cases of DESY and SLAC to further analyze and exemplify this complex set of micro-level change processes that can lead to meso-level renewal. Thereafter, we will return to a discussion of how gradual changes on the micro level and renewal at the meso level relate to institutional persistence and stability of national systems of national laboratories on the macro level.

5.4 Multilevel and Multidimensional Renewal at DESY and SLAC

Both DESY and SLAC were initially founded (in 1959 and 1961, respectively) as single-mission PP laboratories, each with one central piece of infrastructure. The construction and operation of these infrastructures was equal to the laboratory missions such that, in principle, both DESY and SLAC could have ceased to exist following the exhaustion of the scientific opportunities of these original machines.[28] As the laboratories continue to exist today, over 50 years later, we can conclude that this was not the actual course of events. Only a decade after their founding, each laboratory initiated construction projects for new major pieces of infrastructure for PP (see Fig. 5.2),[29] and continued to build several more PP machines for several decades. They also broadened their activities through the layering of a new research mission to operate machines for SR (or PS, as it was later called) on top of their original PP mission. This happened through several changes on the micro level, including changes in the overall scientific programs of the laboratories, in the uses of specific infrastructures and their technical setups and operations, and in the organizational units that were formally responsible for the scientific programs and infrastructures.

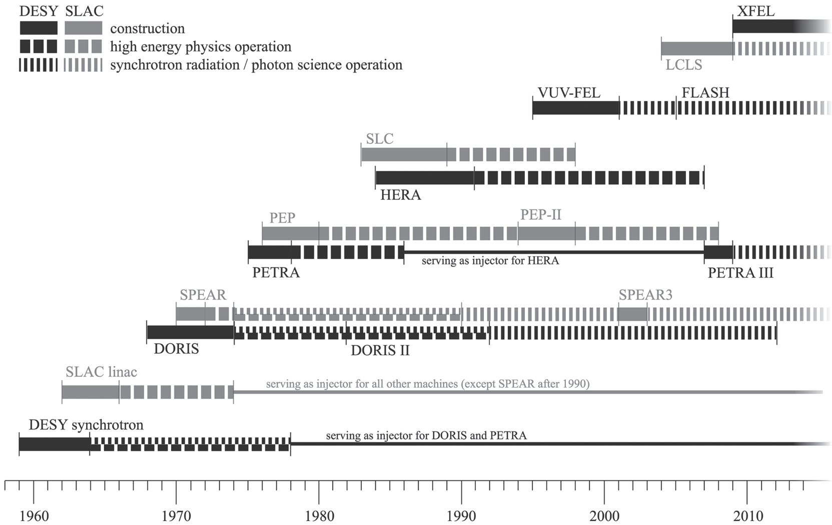

Fig. 5.2 Timeline of major infrastructures at DESY and SLAC, 1959–2015

Although the writing of the histories of these two labs with a one-sided focus on the infrastructures they have operated through the decades is oversimplified and would not give justice to the full range of micro-level processes that together bring about long-term change,[30] it is natural to use the succession of machines as a common thread in the analysis. The infrastructures form a key part of the missions of the labs and constitute powerful symbols of lab identities and culture, but most importantly, they are the key resources in the scientific programs of the laboratories. In the analysis below, clues regarding the combined gradual change processes at the micro level that cumulated into meso-level renewal of the two laboratories are therefore sought by focusing on the infrastructures—other publications use the necessary complementary perspectives.[31] Figures 5.3 and 5.4 illustrate the multilevel transformations of the two laboratories, highlighting their top level and overall 50-year changes (gray shading on the top level). We also point out some particularly evident examples of changes in infrastructure and science on the lower levels, which explain key component processes of the overall transformation (the gray-shaded ellipses lower in the figure). The gray-shaded ellipses should be interpreted as magnifications of those process elements shown with the same gray-shaded

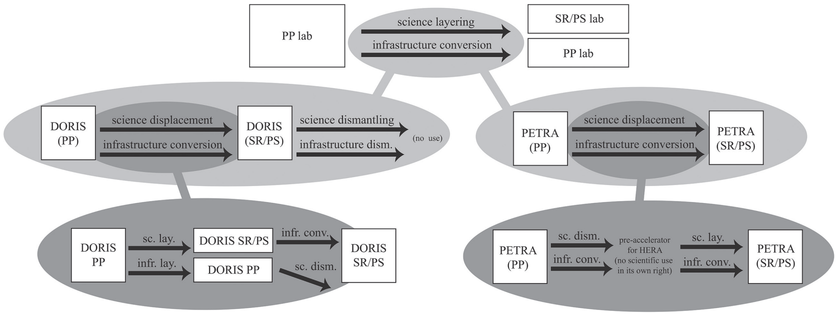

Fig. 5.3 Illustration of some key elements of the multilevel, long-term transformation of DESY with focus on infrastructures

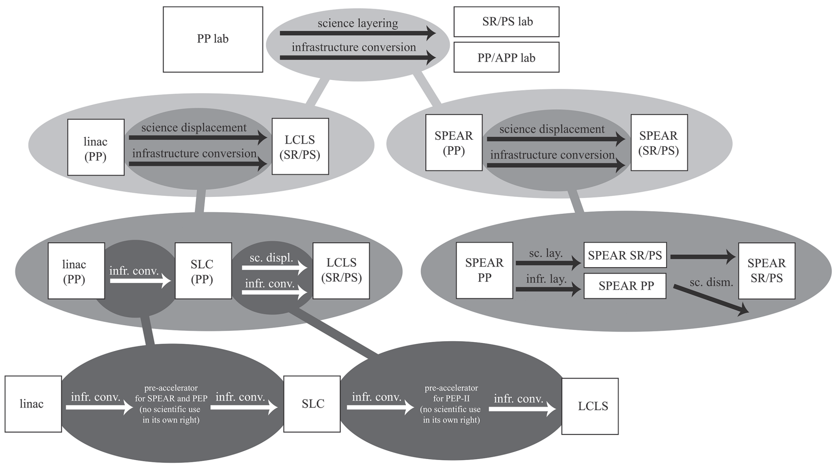

Fig. 5.4 Illustration of some key elements of the multilevel, long-term transformation of SLAC with focus on infrastructures

background on a higher level. They illustrate the increased level of detail that can be seen when analyzing change processes at a detailed level and with shorter time frames. In the second level of the figures, the arrows represent changes on the timescale of decades. On the third level, the arrows represent change processes that typically take a few years.

The overall changes of DESY and SLAC (shown by the top levels of Figs. 5.3 and 5.4) are relatively straightforward. Both started as single-mission PP laboratories with a central laboratory organization and different auxiliary activities conducted by user groups. Organizationally, at both DESY and SLAC, the early SR research comprised of peripheral activities conducted by external user groups that were eventually incorporated into the main laboratory organizations. As organizational units, the synchrotron radiation labs within DESY and SLAC, named HASYLAB (Hamburger Synchrotronstrahlungslabor, Hamburg Synchrotron Radiation Laboratory) and SSRL (Stanford Synchrotron Radiation Laboratory), were founded as distinct entities in the late 1970s, and they became organizational divisions of SLAC (1990s) and DESY (2000s), respectively. Today, DESY still includes a PP division, and SLAC includes a combined APP and PP division. Thus, the 50-year histories of both DESY and SLAC as organizations can be summarized as the addition of SR/PS as a new research mission, which diversifies the former single-mission laboratories (laboratory level: *science layering*).

However, the underlying assumption of this chapter is that DESY and SLAC have been profoundly transformed throughout the past five decades, not merely expanded with the addition of one more layer of activities over an unchanged core mission. We argue that the overall 50-year transformation on the infrastructure side is one of conversion. This premise is based on the facts that both laboratories originally operated scientific infrastructure solely for PP, and both laboratories modified and rebuilt substantial parts of that scientific infrastructure to enable SR/PS (laboratory level: *infrastructure conversion*), and both laboratories are today de facto primarily SR/PS labs in that they operate some of the world's top research infrastructures for SR/PS while not running any PP experiments/machines.

Compared to the analysis of formal organizational changes, the analyses of research infrastructures and scientific fields at the two laboratories are significantly more complex. It must be acknowledged that the organizational changes are unthinkable without the preceding changes to major technical installations and the science around them. The laboratory histories clearly show that a delay preceded their organizational transformations, that is, SR/PS received two formal organizational units/divisions only some time after the scientific–technical change had occurred. It is also important to note that the formal organizational SR/PS units did not replace existing ones, but were instead added on top of existing organizational structures. Due to these factors, the following detailed analysis portrays the organizational side as somewhat less prominent than the other two dimensions (*infrastructure* and *science*), but this is due to a deliberate choice of perspective and emphasis in this chapter.

Figure 5.3 details some key changes to the infrastructure and science of DESY. The science layering and infrastructure conversion at the top level are disaggregated into the analyses of the transformations of key research infrastructures DORIS (Doppel-Ring Speicher, Double Storage Ring) and PETRA (Positron-Elektron Tandem Ringanlage, Positron-Electron Tandem Ring Facility) from DORIS (PP) to DORIS III (SR/PS) and from PETRA (PP) to PETRA III (SR/PS).[32] Both transformations are characterized as processes of simultaneous *science displacement* and *infrastructure conversion* (second level in Fig. 5.3), and then further disaggregated at the machine level (third level in Fig. 5.3). DORIS was originally built as a storage ring for PP, with construction beginning in 1968. Between 1974 and 1992, DORIS was additionally used in parallel for SR in so-called parasitic mode,[33] which required some additional instrumentation (*science layering* and *infrastructure layering*). In 1993, the PP program at DORIS was canceled and the machine became fully dedicated to SR, which means it underwent final *infrastructure conversion* and *science dismantling* (of PP).

PETRA is an even larger storage ring for PP, for which construction began in 1975. In 1986, PETRA was closed for scientific use and turned into a pre-accelerator for the much larger HERA (Hadron-Elektron Ringanlage, Hadron Electron Ring Facility), run until 2007 *(science dismantling* and *infrastructure conversion)*. Later, PETRA was turned into a SR source (PETRA III, *science layering* and *infrastructure conversion*), which eventually, in 2012, made DORIS redundant as a SR facility. At the level of technical infrastructure, the construction of ever-larger machines at DESY over a 50-year time frame can be interpreted as a multistep process of *infrastructure layering* (addition of new machines for PP) and of *infrastructure conversion* (using smaller synchrotrons as injectors for larger storage rings, and dedicating old storage rings to PS) (Fig. 5.2).

Similarly, Fig. 5.4 details some key changes to the infrastructure and science of SLAC. The science layering and infrastructure conversion at the top level are disaggregated into the analyses of the transformations of the key research infrastructures the SLAC original linac and the SPEAR (Stanford Positron-Electron Accelerator Ring) machine, from linac (PP) to LCLS (SR/PS), and from SPEAR (PP) to SPEAR (SR/PS). Both transformations are characterized as processes of simultaneous *science displacement* and *infrastructure conversion* (second level in Fig. 5.4), and then further disaggregated at the machine level (third and fourth levels in Fig. 5.4). The SLAC linac was originally built for PP, but in 1972 it was converted for use merely as a pre-accelerator for other SLAC machines (*infrastructure conversion*). Then, in the 1980s, the linac was used to construct the all-particle physics SLC (SLAC Linear Collider) machine (*infrastructure conversion*). After the SLC closed in the late 1990s, two-thirds of the linac was used as a pre-accelerator for PEP-II (Positron-Electron Project), thus once again undergoing infrastructure conversion, and later, the other one-third was used as a key piece in the construction of the LCLS, which is a state-of-the-art free electron laser machine for PS (yet another instance of *infrastructure conversion*). The LCLS opened for scientific use in 2009. The several-step *infrastructure conversion* from the original 1960s linac to the 2000s LCLS also represents a process of long-term *science displacement* since a key piece of infrastructure previously used solely for PP is now used solely for PS.

SPEAR is a storage ring that was designed and built for use in PP, starting in 1970. The scientific use of SPEAR was soon extended to include a SR program, which required some additional instrumentation (*science layering* and *infrastructure layering*). By the early 1990s, PP research at SPEAR was cancelled in favor of the SR program, which completely took over operations at SPEAR (*science dismantling*). At the level of technical infrastructure, the construction of ever-larger machines at SLAC over a 50-year time frame can be interpreted as a multistep process of *infrastructure layering* (addition of new machines for PP) and of *infrastructure conversion* (using the original linac as an injector for larger machines and dedicating the old storage ring SPEAR to PS) (Fig. 5.2).

We have disaggregated the cases of DESY and SLAC in some detail, in order to exemplify an analysis of micro-level change processes that led to meso-level renewal. The comparison of the two laboratories reveals striking similarities. Both laboratories initiated the construction of storage rings for PP (DORIS and SPEAR) approximately ten years after their founding, which later turned out to be extremely useful for SR research. Viewed from today, when neither one of them is in use for PP anymore, the overall transformation of these storage rings for PP comprises *infrastructure conversion* and *science displacement* (second level, to the right, in Figs. 5.3 and 5.4). On more detailed level, the transformations of DORIS and SPEAR occurred through a gradual addition of SR activities (and associated instrumentation) to the machines (*science layering* and *infrastructure layering*; third level, on the right side, in Figs. 5.3 and 5.4). This was followed by abandonment of the DORIS and SPEAR rings by PP (*science dismantling*), and the concurrent adaptation of the machines for optimized SR operation (*infrastructure conversion*). DORIS was later shut down (*infrastructure dismantling* and *science dismantling*) in 2012, while SPEAR remains in operation, serving the SR user community.

In the late 1970s, both DESY and SLAC built larger storage rings for PP. The SLAC storage ring PEP was almost exclusively used for PP, with only some sporadic SR operations undertaken in the 1980s. PEP was eventually converted into PEP-II and taken out of operation in 2008 (this development is not shown in Fig. 5.4). At DESY, the PETRA storage ring was used solely for PP research for several years, and was then turned into a pre-accelerator for the much larger HERA particle physics machine (*science dismantling* and *infrastructure conversion*; third level, to the left, in Fig. 5.3). Upon the closing of HERA in 2007 (this development is not shown in Fig. 5.3), PETRA was rebuilt into a SR facility (*infrastructure conversion* and *science layering*; third level, on the left side, in Fig. 5.3) and has been used for this purpose since 2009.

The parallels between the changes at DESY and SLAC are further underscored when the machines are displayed on the same timeline (Fig. 5.2). As previously mentioned, at the level of technical infrastructure, the construction of ever-larger machines at both DESY and SLAC over a 50-year time frame can be interpreted as a multistep process of *infrastructure layering* (addition of new machines for PP) and *infrastructure conversion* (using the original machines as injectors for larger machines and dedicating sold storage rings to PS). In each case, this succession culminates in the construction of new infrastructure designed for and dedicated to PS. At DESY, this is the construction and operation of the VUV-FEL (Vacuum-Ultraviolet Free Electron Laser, later renamed FLASH, Free Electron Laser Hamburg) in the late 1990s, and the start of construction of XFEL (X-ray Free Electron Laser) in 2009.[34] At SLAC, this is the 2003–2009 construction of LCLS, which uses parts of the original SLAC linac and thus represents an infrastructure conversion.

While we observe several cases of infrastructure conversion paired with layering of new scientific fields, there are also examples of infrastructure changes that were not combined with respective changes in science. HERA (at DESY) and PEP-II (at SLAC) are examples of dismantling of technical infrastructure that meant science dismantling (of PP activities) on the level of the machines but, importantly, not on the level of the labs. With no future use in sight, HERA was shut down in 2007 and PEP-II in 2008. However, large data sets from experiments at these two machines remained to be analyzed, and thus many particle physicists remained at the two laboratories to complete this work.

All new machines designed and built at DESY and SLAC before the mid-1990s started out as dedicated PP facilities, and all have either been gradually converted into SR facilities (DORIS and SPEAR gradually, PETRA recently and comparably abruptly) or dismantled (PEP and HERA), or both (DORIS). Thus, while we observe several major instances of PP displacement and dismantling at the level of the machines, there has been no equivalent displacement of PP at the laboratory level (yet). PP remains part of their stated core missions, though it is now a somewhat less prominent scientific field. The fact that PP was not immediately dismantled upon closure of the technical infrastructure of this research field shows that scientific programs are only partly tied to infrastructures—appearing to even function independently of them to some extent. This also explains why micro-level change processes in one dimension (e.g., infrastructure) are not necessarily identical to change processes in another dimension (e.g., scientific fields). Of course, one key question is how long the scientific programs of PP can continue without operating a machine. Somewhat speculatively, the material at hand and the analysis above point in the direction of a full eventual displacement of PP, partly by APP and most importantly by SR/PS, seen in long-term and laboratory-level perspective, at both labs.

5.5 Conclusion

This chapter addresses the question of why none of the national laboratories of Germany and the USA have ever been closed, despite considerable changes or even the decline and expiration of their original research missions. The analysis has shown that the answer to this question is complex, since research laboratory renewal is a multilevel and a multitemporal process. We propose that analysis of the complexity of research organizations and their changes requires data spanning several decades, and observations in (at least) three dimensions: technical infrastructures, scientific fields, and organizational units. The combination of these three dimensions within and across certain time windows is necessary to unveil and understand the organizational process of change. Our present analysis touches upon several possible answers, some of which we believe are worthy of more attention in future research.

First, we argue that organizational renewal involves gradual changes at the micro level, which typically do not threaten the existing routines and capacities of research laboratories with regard to technical infrastructure and scientific fields. However, gradual changes can complement each other and, through mutual cumulation over extended periods of time, can lead to reorientations of entire laboratories that go far beyond the short-term small-scale developments. Thus, gradual but cumulative processes of change can have discontinuous effects on the scientific missions of laboratories and their respective research capacities. This link is particularly visible at DESY and SLAC, where we observe a major shift from PP research to PS (although PP remains, and APP has also been added). Although we have not discussed in this chapter what caused these micro-level change processes to occur and then to cumulate, we know from the histories of the two labs that institutional entrepreneurs, laboratory leadership, universities in the vicinity of national laboratories, and federal sponsorship were key elements in explaining how micro-level investments in exploration cumulate into meso-level renewal. Further empirical research is needed to generalize these findings.

Second, the translation of micro-level changes into meso-level renewal is neither automatic nor straightforward, but rather a complex multilevel and multitemporal process. Thus, we would require more knowledge about "failed" laboratories, that is, facilities that have not successfully adapted to changing societal, economic, and political circumstances. In the 1970s, during the consolidation phase of the national laboratories system in the USA, the federal government organized a series of reviews. The aim was to determine whether any research programs within the national laboratories required adaptation, or if perhaps entire laboratories should be closed, as part of the government downsizing promised by the Reagan administration. Silicon Valley entrepreneur David Packard headed one of these review panels, and reportedly "chilled the hearts of laboratory directors across the nation"[35] by saying "Preservation of the laboratory is not a mission."[36] This statement is clearly provocative, but there is little empirical evidence to substantiate it. As no laboratories were ultimately closed, the question remains under which institutional conditions laboratories fail to translate micro-level changes into meso-level renewal, and what consequences this has on their scientific productivity and impact.

Third, we have argued that macro-level stability is related to both micro-level and meso-level changes within and across single laboratories. Our present analyses provide no conclusive evidence demonstrating which level is more important in this regard. The transformations of DESY and SLAC evidently support the claim that successful adaptations at the meso level tend to stabilize the laboratory systems as a whole. However, since DESY and SLAC each represent only one laboratory in their respective national systems, we cannot generalize this statement without providing supportive empirical evidence relating to the other 16 German and 9 US laboratories. Still, we know that micro-level changes have occurred in one way or another in all national laboratories in these two countries. As mentioned above, since the consolidation phase of each national laboratory system, their budget growth has typically been consumed by existing laboratories but not by new ones. Additionally, the original national laboratories had core research missions of nuclear energy or nuclear energy-related R&D, but their research portfolios later broadened considerably into areas including chemical and molecular science, biological systems science, climate change science, applied materials science and engineering, chemical engineering, computer science, biotechnology, and APP. Therefore, it seems that micro-level changes in single national laboratories have provided the macro-level system with enough adaptive capacity to survive despite considerable macro-level changes in research policy and society at large, such as those brought on by the end of the Cold War.

The explanation of how micro-level adaptation and meso-level renewal influence macro-level stability or change, and vice versa, is key to understanding institutional change in national laboratory systems. One possibility is that micro-level changes in single national laboratories have provided the macro level with enough adaptive capacity to maintain its status quo (i.e., the survival of all national laboratories ever founded). The outcome of this situation would be very different compared to a situation where micro-level changes cumulate into meso-level renewal, thus providing the macro level with renewability and survival capacity. System level reproduction by micro-level adaptation is quite different from system level transformation by meso-level renewal. Although we know that the two national laboratory systems have survivor qualities, we do not yet know whether the renewal of DESY and SLAC can be generalized to other national laboratories. This challenging question remains on the agenda for future research.

Notes

1. Daniel S. Greenberg, *The Politics of Pure Science,* 2nd ed. (Chicago, IL: University of Chicago Press, 1999/1967); Peter J. Westwick, *The National Laboratories: Science in an American System 1947–1974* (Harvard University Press, 2003); Bruce L. R. Smith, *American Science Policy since World War II* (Washington, DC: Brookings Institute, 1990).
2. For the US case, we delimit the analysis to those National Laboratories that have civilian missions and civilian oversight in the shape of the Office of Science of the United States Department of Energy (DOE). The seven weapons laboratories are excluded from the analysis since their activities and organizations are classified (secret) and thus do not lend themselves to this type of study. For obvious historical reasons, a similar delimitation is not necessary in the German case, where no weapons laboratories of the same sort exist.
3. Olof Hallonsten, "The parasites: Synchrotron radiation at SLAC, 1972–1992," *Historical Studies in the Natural Sciences* 45, no. 2 (2015); Thomas Heinze, Olof Hallonsten, and Steffi Heinecke, "From Periphery to Center. Synchrotron radiation at DESY, Part I: 1962–1977," *Historical Studies in the Natural Sciences* 45, no. 3 (2015a); Thomas Heinze, Olof Hallonsten, and Steffi Heinecke, "From Periphery to Center. Synchrotron radiation at DESY, Part II: 1977–1993," *Historical Studies in the Natural Sciences* 45, no. 4 (2015b).
4. Robert P. Crease, "The National Synchrotron Light Source, Part I: Bright Idea," *Physics in perspective* 10 (2008); Robert P. Crease, "The National Synchrotron Light Source, Part II: The Bakeout," *Physics in perspective* 11 (2009); Park Doing, *Velvet Revolution at the Synchrotron: Biology, Physics, and Change in Science* (Cambridge, MA: MIT Press, 2009); Olof Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41, no. 2 (2011); Olof Hallonsten and Thomas Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42, no. 6 (2015); Catherine Westfall, "Retooling for the Future: Launching the Advanced Light Source at Lawrence's Laboratory, 1980–1986," *Historical Studies in the Natural Sciences* 38, no. 4 (2008b); Catherine Westfall, "Institutional Persistence and the Material Transformation of the US National Labs: the Curious Story of the Advent of the Advanced Photon Source," *Science and Public Policy* 39, no. 4 (2012).
5. The chapter partly draws on material published in Olof Hallonsten and Thomas Heinze, "Institutional persistence through gradual adaptation: Analysis of national laboratories in the USA and Germany," *Science and Public Policy* 39 (2012): 436; and Olof Hallonsten and Thomas Heinze,

"From particle physics to photon science: Multidimensional and multilevel renewal at DESY and SLAC," *Science and Public Policy* 40, no. 5 (2013).

6. Before 1974, the Atomic Energy Commission (AEC); between 1974 and 1977, the Energy Research and Development Administration (ERDA); since 1977, the DOE.
7. Westwick, *National Laboratories;* Michael Crow and Barry Bozeman, *Limited by Design. R&D Laboratories in the U.S. National Innovation System* (New York: Columbia University Press, 1998).
8. Hans-Willy Hohn and Uwe Schimank, *Konflikte und Gleichgewichte im Forschungssystem: Akteurkonstellationen und Entwicklungspfade in der staatlich finanzierten außeruniversitären Forschung* (Frankfurt, Germany: Campus, 1990), 39–62; Thomas Heinze "Trends und Entwicklungslinien der außeruniversitären Forschung im internationalen Vergleich," in *Wissenschaft als Beruf. Bestandsaufnahme—Diagnosen—Empfehlungen*, ed. M. Haller (Wien: Österreichische Akademie der Wissenschaften, 2013).
9. Thomas Heinze and Natalie Arnold, "Governanceregimes im Wandel. Eine Analyse des außeruniversitären, staatlich finanzierten Forschungssektors in Deutschland," *Kölner Zeitschrift für Soziologie und Sozialpsychologie* 60 (2008).
10. Hallonsten and Heinze, "Institutional persistence," 436.
11. Ibid., 452–53.
12. Richard G. Hewlett and Oscar E. Anderson, Jr., *A History of the United States Atomic Energy Commission. Volume 1. The New World, 1939/1946* (University Park, PA: Pennsylvania State University Press, 1962), 714–22; Terrence R. Fehner and Jack M. Holl, *Department of Energy 1977–1994. A Summary History* (Washington, DC: United States Department of Energy, 1994), 11.
13. Jack M. Holl, *Argonne National Laboratory 1946–96* (Chicago, IL: University of Illinois Press, 1997), 279; Catherine Westfall, "Surviving the squeeze: National laboratories in the 1970s and 1980s," *Historical Studies in the Natural Sciences* 38 (2008a): 476.
14. Hallam Stevens, "Fundamental physics and its justifications, 1945–1993," *Historical Studies in the Physical and Biological Sciences* 34 (2003): 161; Westwick, *National Laboratories*, 269.
15. David H. Guston, "Stabilizing the boundary between US politics and science: The role of the Office of Technology Transfer as a boundary organization," *Social Studies of Science* 29 (1999): 94; Ann Johnson, "The end of pure science: Science policy from Bayh–Dole to the NNI," in *Discovering the Nanoscale*, ed. D. Baird et al. (Amsterdam, the Netherlands: IOS Press, 2004); Westfall, "Surviving the squeeze."
16. Michael Riordan, Lillian Hoddeson, and Adrienne W. Kolb, *Tunnel Visions. The Rise and Fall of the Superconducting Super Collider* (Chicago, IL; University of Chicago Press, 2016), p. 201–247.

17. Gerhard A. Ritter, *Großforschung und Staat in Deutschland. Ein historischer Überblick* (München, Germany: Beck, 1995), 56–77.
18. Hohn and Schimank, *Konflikte und Gleichgewichte*, 262–95; Ritter, *Großforschung und Staat*, 100–11.
19. Heinze and Arnold, "Governanceregimes"; Sabine Helling-Moegen, *Forschen nach Programm. Die programmorientierte Förderung in der Helmholtz-Gemeinschaft: Anatomie einer Reform* (Marburg: Tectum Verlag, 2009); Insa Pruisken, *Fusionen im institutionellen Feld 'Hochschule und Wissenschaft'* (Baden-Baden: Nomos, 2014), 157–81.
20. Robert P. Crease, *Making Physics: A Biography of Brookhaven National Laboratory, 1946–1972* (Chicago: The University of Chicago Press, 1999); Holl, *Argonne National Laboratory*; Leland Johnson and Daniel Schaffer, *Oak Ridge National Laboratory: The First Fifty Years* (Memphis, TN: The University of Tennessee Press, 1994); Westwick, *National Laboratories.*
21. Ritter, *Großforschung und Staat*; Claus Habfast, *Großforschung Mit Kleinen Teilchen. Das Deutsche Elektronen-Synchrotron Desy 1956–1970* (Heidelberg: Springer Verlag, 1989).
22. James Mahoney, "Path Dependence in Historical Sociology," *Theory and Society* 29 (2000); Paul Pierson, *Politics in Time: History, Institutions, and Political Analysis* (Princeton, NJ: Princeton University Press, 2004).
23. Kathleen Thelen, "How institutions evolve. Insights from comparative historical analysis," in *Comparative Historical Analysis in the Social Sciences*, ed. J. Mahoney, and D. Rueschemeyer (New York: Cambridge University Press, 2003); Wolfgang Streeck and Kathleen Thelen, "Introduction: Institutional change in advanced political economies," in *Beyond Continuity. Institutional Change in Advanced Political Economies*, ed. W. Streeck, and K. Thelen (Oxford, UK: OUP, 2005); Wolfgang Streeck, *Re-Forming Capitalism. Institutional Change in the German Political Economy* (Oxford, UK: OUP, 2009).
24. Hallonsten and Heinze, "Institutional persistence."
25. Figure 5.1 is an adapted version of the one published in Hallonsten and Heinze, "From particle physics to photon science."
26. See, for example, Westfall, "Surviving the squeeze."; Stevens, "Fundamental physics," 183–96; Daniel Kevles, "Big Science and big politics in the United States: Reflections on the death of the SSC and the life of the Human Genome Project," *Historical studies in the physical and biological sciences* 27, no. 2 (1997).
27. Holl, *Argonne National Laboratory*, 46; Westfall, "Surviving the squeeze"; Helling-Moegen, *Forschen nach Programm*; Pruisken, *Fusionen*, 157–81.
28. Wolfgang K.H. Panofsky, *Panofsky on Physics, Politics, and Peace: Pief Remembers* (New York: Springer, 2007), 126; Erich Lohrmann and Paul

Söding, *Von schnellen Teilchen und hellem Licht: 50 Jahre Deutsches Elektronen-Synchrotron DESY*, 2nd edition (Berlin: Wiley, 2013), 1–19.

29. Figure 5.2 shows a combined and updated version of two figures published in Hallonsten and Heinze, "From particle physics to photon science," 594, 597.
30. Hallonsten, "The parasites."
31. Hallonsten, "The parasites"; Heinze, Hallonsten, and Heinecke, "DESY, Part I."; Heinze, Hallonsten, and Heinecke, "DESY, Part II."
32. Note that the infrastructure conversion of upgrading individual machines often coincided with name changes, such as the upgrade from DORIS to DORIS II. For reasons of clarity, we use only the main names and not the names of individual versions in Figs. 5.3 and 5.4.
33. For details on this term, see Hallonsten, "The parasites," 219.
34. Although, for the sake of stringency and correctness, it should be noted that the XFEL is not part of DESY but a stand-alone company owned by 12 European governments through their respective research councils and ministries. The German share of 58% of the company is administered by DESY which acts as the German government's representative in the XFEL governing bodies, and part of the XFEL is also physically located to the DESY site, which means that the XFEL in practice (though not legally) is partly integrated into the DESY organization. Olof Hallonsten, "The Politics of European Collaboration in Big Science," in *The Global Politics of Science and Technology—Vol. 2, Global Power Shift*, ed. M. Mayer, M. Carpes, and R. Knoblich (Berlin: Springer, 2014).
35. Westfall, "Retooling for the Future," 571.
36. Holl, *Argonne National Laboratory*, 401.

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