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Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System

ABSTRACT

MAX-lab is a Swedish national synchrotron radiation facility, first established as a small-scale university project in the late 1970s and then gradually developed into a national and international user facility. This article presents a historical study of MAX-lab that illustrates the decentralized character of the Swedish science policy system and especially its lack of aggregation mechanisms for strategically important initiatives such as the establishment of large research infrastructures. The dominating university sector and the absence of strong central governance structures have made Swedish science policy pluralistic, driven from the bottom up, and decentralized. The genesis and development of MAX-lab, while remarkable when compared to other such facilities internationally, is symptomatically Swedish—it has grown from the bottom up and step by step, and thereby managed to become a respected national and international user facility despite unfavorable conditions. The patchy funding model and the lack of coherent policymaking has led to underfunding and an opaque organizational

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The following abbreviations are used: AFR, Atomforskningsrådet (Atomic Research Council), Stockholm, Sweden; ALS, Advanced Light Source; ESO, European Southern Observatory, La Silla, Chile; ESRF, European Synchrotron Radiation Facility, Grenoble, France; FRN, Forskningsrådsnämnden (National Council for Planning and Coordination of Research), Stockholm, Sweden; KAW, Knut and Alice Wallenberg Foundation, Stockholm, Sweden; KFI, Kommittén för Forskningens Infrastrukturer (Committee for Research Infrastructures), Stockholm, Sweden; LU, Lund University, Lund, Sweden; LUSY, Lund University Synchrotron; NFR, Naturvetenskapliga Forskningsrådet (Natural Science Research Council), Stockholm, Sweden; *NIM, Nuclear Instruments and Methods*; *NIMPR, Nuclear Instruments and Methods in Physics Research*; NSLS, National Synchrotron Light Source; OSO, Onsala Space Observatory, Onsala, Sweden; PRT, Participating Research Team; SEK, Swedish krona; TFR, Teknikforskningsrådet (Technical Sciences Research Council), Stockholm, Sweden; TSL, Svedberg Laboratory, Uppsala, Sweden; UHÄ, Swedish National Board of Universities and Colleges; VR, Vetenskapsrådet (Swedish Research Council); VUV, vacuum ultraviolet.

Historical Studies in the Natural Sciences, Vol. 41, Number 2, pps. 179–215. ISSN 1939-1811, electronic ISSN 1939-182X. DOI: 10.1525/hsns.2011.41.2.179.

structure, but MAX-lab and its users have nonetheless been of high quality. This article argues that the determination, patience, adaptivity, and, to some extent, ingenuity of the people involved in MAX-lab have compensated for systemic shortcomings and enabled the laboratory to succeed despite the unfavorable conditions.

KEY WORDS: synchrotron radiation laboratories, Swedish research policy, MAX-lab, resource allocation in science, user-driven infrastructure projects, big science

The MAX laboratory, commonly referred to as MAX-lab, is a Swedish national research facility for synchrotron radiation and nuclear physics, located in Lund in southern Sweden.[1] Officially inaugurated in 1987 after more than a decade of construction, MAX-lab has continuously expanded and developed from a small-scale university project to a national resource and international user facility, with approximately 600 synchrotron radiation users annually. The laboratory is located on the campus of the Lund Institute of Technology (part of Lund University, LU) and has a dual organizational status: it is a Swedish National Research Facility, under supervision of the Swedish Research Council (Vetenskapsrådet, VR), and it is affiliated with LU, as a department under the Office of the Vice-Chancellor. Among the many incremental upgrades in the laboratory's history, the MAX II project stands out as the largest and most important to date.[2] The nuclear physics program, originally the laboratory's main activity, has gradually taken a back seat during the past decades as the synchrotron radiation activities have expanded in scope and scale. This article is focused on the synchrotron radiation program at MAX-lab, which dominates the lab's scientific activities.

While MAX-lab compares favorably with several of the most prominent synchrotron radiation facilities around the world in size and number of users,

1. Opinions differ regarding the original meaning of the name MAX laboratory, and there is no mention of an explanation either in the first published technical report on the accelerator or in the official history of the laboratory. Mikael Eriksson, "The Accelerator System MAX," *NIM* 196 (1982): 331–40; Bengt Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund, Sweden: Lund University, 2001). Some claim that MAX is an acronym for "Microtron Accelerator for X-ray production." Per-Olof Nilsson, interview by author, Gothenburg, 5 Sep 2008. Others suspect the name has something to do with the founder, Bengt Forkman, whose birthday is on February 1, which is the name day of Max in the Swedish almanac. Mikael Eriksson, interview by author, Lund, 17 Mar 2006.

2. The accelerators at MAX-lab are numbered in chronological order—MAX I, MAX II, and MAX III. MAX II is the largest accelerator and thus the main ring at the present-day laboratory; MAX III is significantly smaller but newer and hence its name.

its history differs from most of its counterparts in the United States and continental Europe (see tables 1 and 2 below). MAX-lab has grown to its current size and shape through a series of incremental steps and the work of skilled and ambitious individuals in and around the laboratory, rather than by discontinuous funding or policy decisions. This article accounts for the history of MAX-lab and argues that the dynamic and modular character of synchrotron radiation laboratories makes such a gradual expansion possible, but also that the character of the development of the small-scale university project into a valuable national resource is symptomatically Swedish. Though the only one of its kind in Sweden, the laboratory embodies salient features of the Swedish science policy system: decentralization, indecision, and lack of strategic priority. Because it has been the result of manuevering by its proponents and advocates through the seemingly unfavorable Swedish science policy system rather than the consequence of deliberate and coherent policymaking, MAX-lab is remarkable when compared to other facilities of its kind outside of Sweden.

CONTEXT AND ORIGINS

Synchrotron Radiation

Research with synchrotron radiation is tied to experimental particle physics by the simple fact that they both make use of the same basic technology—particle accelerators; however, on technical and scientific levels, the similarity ends there. While particle physics accelerator laboratories have a clearly defined central purpose and currently employ thousands of researchers and engineers on single experiments running for several years, synchrotron radiation laboratories essentially support a large body of very diverse "small science" activities. The experimental facilities at synchrotron radiation laboratories are mostly used by research groups from academia and other institutions for short periods, and several such groups from varying fields work simultaneously on the laboratory floor with different experimental setups.

Synchrotron radiation is produced by circular accelerators (the result of an inevitable energy loss of the accelerated elementary particles) and consists of very intense radiation, primarily wavelengths in the ultraviolet and x-rays spectrum. The radiation, continuously produced by the particles along the whole circular accelerator, is led through *beamlines* to different instruments that are specialized for experimental work in various branches of physics, materials science, chemistry, biology, the life sciences, and environmental sciences.

Beginning in the 1960s, exploratory programs in synchrotron radiation research were carried out at particle physics laboratories in Europe, Japan, and the United States, in "parasitic" or "pirate" mode.[3] Since then, continuous technological advances on virtually all components of synchrotron radiation facilities have been matched by a gradual development of scientific communities' demands for, and capabilities to utilize, synchrotron radiation. It has, hence, been transformed from a small laboratory curiosity to a mainstream experimental technique for a wide selection of natural sciences. Dedicated and specialized synchrotron radiation laboratories began to emerge in the 1970s and have replaced "parasitic" programs. In 2009, approximately forty dedicated synchrotron radiation user facilities were in operation worldwide, serving several tens of thousands of annual users.[4] The size and scientific scope of the laboratories vary widely, and small accelerators can be built to serve local or regional scientific communities while also managing to compete globally in specialized areas.

Arguably one of the most significant developments in synchrotron radiation has been the growth of life sciences applications, made possible primarily by the introduction of *insertion devices*, which allow for the production and utilization of *hard x-rays* at synchrotron radiation laboratories.[5] Simultaneously, ultraviolet (abbreviated VUV, vacuum ultraviolet) and soft x-ray applications, in physics, chemistry, and some areas of materials science, have also expanded.[6]

3. Among early synchrotron radiation practitioners, "parasites" was a common term for their status at the labs—e.g., Herman Winick and Arthur Bienenstock, "Synchrotron Radiation Research," *Annual Review of Nuclear and Particle Science* 28 (1978): 33–113, on 37; Ednor M. Rowe, "Some Reflections on the Growth of Synchrotron Radiation Research," *NIM* 152 (1978): 331–33. Others used the term "pirates"—e.g., P. L. Hartman, "Introductory Remarks," *NIM* 195 (1982): 1–6.

4. These figures are approximate and derived from information about synchrotron radiation laboratories and their users at www.lightsources.org. They should be taken only as rough estimates to provide a general picture, and not considered an exact measure.

5. Insertion devices are arrays of magnets inserted in straight sections of accelerators that make the particles wiggle and undulate back and forth and up and down—the two chief types are consequently called wigglers and undulators—and that can be optimized for radiation production in different wavelength spectra. Gopal Shenoy, "Basic Characteristics of Synchrotron Radiation," *Structural Chemistry* 14 (2003): 3–14, on 7–9.

6. Soft and hard x-rays denote x-ray radiation below and above the wavelength of a few angstrom (10^{-10} m). They are referred to as soft and hard originally because of their penetrating capabilities; hard x-rays have shorter wavelengths and penetrate matter with more force. James Long,

During the 1980s and '90s, these two broad categories of wavelengths—hard x-rays on one hand and VUV/soft x-rays on the other—caused a clear divide within synchrotron radiation laboratories with regard to accelerator designs and scientific focus. The hard x-rays labs required significantly larger accelerators, and three major labs with this explicit focus were planned and built in Europe, Japan, and the United States.[7] Complementing these major labs, and within the financial capabilities of smaller countries, were the VUV/soft x-ray sources, of which MAX-lab is an example. The two wavelength ranges and thus the two types of synchrotron radiation sources corresponded roughly to the needs of two different user communities, with (most of) physics utilizing VUV and soft x-rays and (most of) biology and chemistry utilizing hard x-rays. In the 1990s, the distinction gradually became obsolete as developments in accelerator technology, particularly regarding insertion devices, made possible the production of hard x-rays by the old VUV/soft x-ray sources and vice versa, and during the past decade a new type of accelerator optimized for both regimes has emerged as the preferable design for new synchrotron radiation laboratories throughout the world.[8]

The technical and scientific improvements that made synchrotron radiation a mainstream experimental resource were complemented by sociological developments in lab organizations to accommodate a diverse and growing user community. Very dissimilar activities have been simultaneously carried out at synchrotron radiation laboratories—some take weeks and require specialized technical competence, and some can be reduced to sample switching on standardized equipment or even web-based remote control. The wide variation of scientific areas and instrumentation also makes the laboratory environment dynamic and interchangeable: experimental setups can be replaced, and new applications that emerge years after an accelerator has been placed into operation can be exploited by adding new instruments to the basic infrastructure. There is hence a built-in contingency—as the story of MAX-lab will show,

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"X-ray Microanalysis," in *X-rays: The First Hundred Years*, ed. Alan Michette and Slawka Pfauntsch (New York: John Wiley & Sons, 1996), 61–100, on 61.

7. The Advanced Photon Source (APS) at Argonne National Laboratory in Illinois, the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, and the SPring-8 (Super Proton ring 8 GeV) in Harima, Japan. Herman Winick, *Synchrotron Radiation Sources: A Primer* (London: World Scientific, 1994), 7.

8. Donald H. Bilderback, Pascal Elleaume, and Edgar Weckert, "Review of Third and Next Generation Synchrotron Light Sources," *Journal of Physics B: Atomic, Molecular and Optical Physics* 38 (2005): S773–S797.

whole scientific areas that were not part of the original plans or scientific foundation for a facility might be added later. Synchrotron radiation laboratories can therefore be constructed incrementally, and the commitment of initiating construction does not have to encompass a full anticipation of what the laboratory will eventually become; in fact, the built-in contingency often makes such anticipation impossible.[9]

Thus the sociology of synchrotron radiation laboratories is radically different from that of particle physics laboratories, as are their purpose and function in the scientific landscape. There are, however, important political and sociological connections between them; not only was the first exploratory work with synchrotron radiation carried out by "parasites" or "pirates" at particle physics labs, but later developments in particle physics also paved the way for the expansion of synchrotron radiation in many countries. Authors have claimed that the great leap in size of particle physics accelerators in the 1960s and '70s marked the step from big science to "megascience," in a purely physical sense as well as sociologically.[10] The transformation into "megascience" caused a monopolization of particle physics funding resources by very large institutions such as the European Organization for Nuclear Research (CERN), Fermi National Accelerator Laboratory (Fermilab), and Stanford Linear Accelerator Center (SLAC) in the United States, and the High Energy Physics Institute (KEK) in Japan.[11] In many cases, this led to the desertion of smaller accelerators at laboratories across the European and American continents and in Japan; these accelerators could be turned into synchrotron radiation facilities or, when not sufficiently high-performing, be replaced by machines purpose-built for synchrotron radiation by the accelerator physicists left behind at the sites.[12] In part, MAX-lab has this development

9. For extensive accounts on the history of synchrotron radiation and a full development of this contingency argument, see Olof Hallonsten, "Small Science on Big Machines: Politics and Practices of Synchrotron Radiation Laboratories" (PhD dissertation, Lund University, Lund, Sweden, 2009).

10. Lillian Hoddeson, Adrienne W. Kolb, and Catherine Westfall, *Fermilab: Physics, the Frontier and Megascience* (Chicago and London: University of Chicago Press, 2008), 3, 281, 309–11; Mark Bodnarczuk and Lillian Hoddeson, "Megascience in Particle Physics: The Birth of an Experiment String at Fermilab," *Historical Studies in the Natural Sciences* 38, no. 4 (2008): 508–34.

11. John Krige, "The Relationship Between CERN and Its 'Visitors' in the 1970s," in *History of CERN: Volume III*, ed. John Krige (Amsterdam: Elsevier, 1996), 171–206, on 199; Lillian Hoddeson, "Establishing KEK in Japan and Fermilab in the U.S.: Internationalism, Nationalism and High Energy Accelerators," *Social Studies of Science* 13 (1983): 1–48.

12. I. H. Munro, "Synchrotron Radiation Research in the UK," *Journal of Synchrotron Radiation* 4 (1997): 344–58, on 346; Catherine Westfall, "Retooling for the Future: Launching the

to thank for its existence, as Sweden's increased commitment to CERN stripped the accelerator group in Lund of its resources and forced it to search out new areas of application for their machine development.

The Swedish Science Policy System

In 1954, when physicists established CERN, the European collaboration in particle physics, it was complementary to national efforts in the field and supposed to be the "apex of a pyramid whose base comprised the national laboratories."[13] But CERN's step to "megascience" through the very costly CERN II upgrade, adopted in 1972, had the effect that all member states except the Federal Republic of Germany directed their total expenditures on particle physics to CERN, at the expense of national programs.[14] In Sweden, this meant the termination of the experimental particle physics program in Lund, but the debate that preceded Swedish participation in CERN II also brought to light a general shortcoming in the Swedish science policy system that is key to the contextual explanation of the genesis and development of MAX-lab.

The immediate postwar decades had seen a Swedish development in science and science policy similar to most Western countries of comparable size, with strong growth and an intensified relationship between the scientific establishment and the government. However, Swedish neutrality and the self-sufficiency doctrine in the 1940s, '50s, and '60s focused the efforts of the government on the university system, where breadth could be maintained and where education remained the top priority. Included in this policy was the institution of "floor funding" to the universities as the primary channel for governmental funding of research. This money was distributed among scientific areas by decision of parliament and thus passed over university chancellors on its way to the departments and institutes.[15] In addition, a number of research councils were

Advanced Light Source at Lawrence's Laboratory, 1980–1986," *Historical Studies in the Natural Sciences* 38, no. 4 (2008): 569–609.

13. Krige, "Relationship" (ref. 11), 199.

14. John Krige, "The Politics of European Scientific Collaboration," in *Companion to Science in the Twentieth Century*, ed. John Krige and Dominique Pestre (London: Routledge, 2003), 897–918, on 905; John Krige, "CERN from the Mid-1960s to the Late 1970s," and Dominique Pestre, "The Difficult Decision, Taken in the 1960s, to Construct a 3-400 GeV Proton Synchrotron in Europe," both in Krige, ed., *History of CERN: Volume III* (ref. 11), 3–38, on 33, and 65–96, on 67–68, resp.

15. Until the mid-1980s, approximately two-thirds of the universities' research budgets were covered by floor funding from the government, a figure that has gradually decreased since then

launched, corresponding to broad disciplinary areas and run by scientists elected by the community. Together, these policies created a pluralistic and in some sense democratic system, placing the real power over Swedish science in the hands of its practitioners, but the policies failed to establish steering mechanisms on a central level that could balance the otherwise distributed governance and take responsibility for discontinuous and strategic choices.[16] This limitation was exposed when Sweden prepared to decide whether to join in the CERN II upgrade, a commitment that would mean at least a twofold increase in Sweden's annual financial contribution to CERN and thus would require strategic initiative and decision-making at a central political level.[17] A bewildering and tortuous debate followed, characterized both by confusion regarding who was to make the final decision and by the lack of political ability or will to point the way in any specific direction. The matter was only resolved when the prime minister, Olof Palme, referred it back to the scientific community, demanding that scientists take responsibility for their own priorities, i.e., find money for CERN II participation within existing budgets.[18] This doctrine has since been institutionalized, with the effect that the already decentralized system has been further weakened. With the government assuming a passive role, the only instance where national priorities can be set is within the research councils, but these are not equipped for that kind of decision-making (to be discussed below). The whole system suffers from a lack of "aggregation mechanisms," i.e., institutional means of mobilizing resources or support apart from the ones developed by the scientists and research groups themselves, which has made strategic commitments to specific areas or projects practically nonexistent.[19]

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and is currently below 50%. Anonymous, "Högre utbildning och forskning 1945–2005—en översikt" (2006), Swedish National Agency for Higher Education, Report 2006:3 R, 41–42.

16. Fredrik Melander, "Lokal Forskningspolitik: Institutionell Dynamik och Organisatorisk Omvandling vid Lunds Universitet 1980–2005" (PhD dissertation, Lund University, Lund, 2006), 133; Rune Premfors, *Svensk Forskningspolitik* (Lund: Studentlitteratur, 1986), 13–41; Torsten Nybom, *Kunskap—Politik—Samhälle: Essäer om kunskapssyn, universitet och forskningspolitik 1900–2000* (Hargshamn: Hjalmar & Jörgen Bokförlag, 1997), 101.

17. Axel Hadenius, *Sweden and CERN II: The Swedish Research Policy Debate* (Stockholm: The Committee on Research Economics, 1972), 10, 21.

18. Sven Widmalm, "Big Science in a Small Country: Sweden and CERN II," In *Center on the Periphery: Historical Aspects of 20th-Century Swedish Physics,* ed. Svante Lindqvist (Canton: Watson Publishing International, 1993), 107–40, on 110, 121.

19. Mats Benner and Ulf Sandström, "Inertia and Change in Scandinavian Public-Sector Research Systems: The Case of Biotechnology," *Science and Public Policy* 27, no. 6 (2000): 443–54, on 444; Mats Benner, *Kunskapsnation i kris? Politik, pengar och makt i svensk forskning* (Stockholm: Nya Doxa, 2008), 222.

The CERN membership and similar large-scale commitments have been kept in force largely by default.

Occasional attempts have been made to create "aggregation mechanisms" in the system. The National Council for Planning and Coordination of Research (Forskningsrådsnämnden, FRN), created in 1977 and deliberately detached from the discipline-based council structure, was given the explicit mission to commit to the funding of discontinuous trans- or interdisciplinary projects, such as research infrastructure.[20] Consequently, FRN did play a critical role in the 1990s upgrades of MAX-lab, a matter that will be discussed below. It was abolished in 2001, when the four discipline-based research councils (for humanities and social sciences, medicine, natural sciences, and technical sciences) were merged into a single agency, the VR. This merger was motivated by an ambition to increase coherence and coordination, but since the council is still governed by scientists and made up of three scientific subcouncils (for medicine, natural and technical sciences, and humanities and social sciences) with their own discrete budgets, the effect was arguably the opposite—with FRN abolished, the room for larger strategic commitments or priorities was only reduced.[21] The 2005 creation of the Research Council's Committee for Research Infrastructures (Kommittén för Forskningens Infrastrukturer, KFI) was an attempt to highlight the importance of equipment and facilities in science, but the committee's work has been concentrated on coordination rather than decision-making or prioritization. This is only natural, since the budget of the committee is still contained through the ordinary funding procedure from the government to the council. Within the zero-sum game of this budget is contained all Swedish membership fees for international collaborations, such as CERN, the European Southern Observatory (ESO), ESRF, and thirteen others, as well as the budgets of the two Swedish national facilities (MAX-lab and Onsala Space Observatory, OSO).[22]

The Early MAX

As mentioned above, Sweden's 1972 decision to participate in the CERN II upgrade meant the discontinuation of governmental funding to accelerator

20. Benner, *Kunskapsnation i kris?* (ref. 19), 361; Premfors, *Svensk Forskningspolitik* (ref. 16), 28.

21. Melander, "Lokal Forskningspolitik" (ref. 16), 138; Benner, *Kunskapsnation i kris?* (ref. 19), 298–99, 382.

22. Per Karlsson, interview by author, Stockholm, 19 Mar 2007; Anonymous, "Vetenskapsrådet Årsredovisning 2007" (2008), VR Annual Report, 32, 76.

projects for particle physics in Sweden, among which the project LUSY (Lund University Synchrotron) was prominent. The particle physics group at LU had started operation of the synchrotron in 1962, and a 1970 grant from the Swedish Natural Science Research Council (Naturvetenskapliga Forskningsrådet, NFR) had allowed for some exploratory work with synchrotron radiation from LUSY. At the instigation of a physicist from Chalmers Institute of Technology in Gothenburg, Per-Olof Nilsson, some experimental work in solid-state physics was conducted with the radiation, but ended when LUSY received its shutdown decision.[23] But word of synchrotron radiation and its possible applications had also reached Sweden from abroad, and in 1975 a conference was organized in Gothenburg with the aim of spreading knowledge about synchrotron radiation in the scientific communities and making preliminary plans for a future Swedish or Nordic synchrotron radiation facility. Invited speakers from synchrotron radiation programs abroad reported on developments in their respective countries and about successful experiments done at existing facilities, and representatives from the LUSY project briefed the conference about their work. Most participants showed lukewarm interest, questioning the value of synchrotron radiation to their respective fields and the potential level of interest in Sweden or the Nordic countries, but the possibility of a Swedish initiative in synchrotron radiation was not completely ruled out.[24]

Meanwhile in Lund, the nuclear physicists had started planning for their future after the complete dismantling of LUSY. Shifting focus from particle physics to other possible accelerator-based work in nuclear physics, they settled for a comparably inexpensive but still scientifically interesting device, the "pulse stretcher."[25] The project, given the name MAX, was granted money from the Swedish Atomic Research Council (Atomforskningsrådet, AFR) in 1976, and by this grant an uninterrupted accelerator activity in Lund was secured, since construction of the MAX accelerator could be initiated one year before the final dismantling of LUSY was completed. To build the MAX machine, a newly

23. Anonymous, "Rapport från NFR:s arbetsgrupp för granskning av förslag om europeisk synkrotronljuskälla" (1980), NFR Report, 2; Forkman, *Och det blev ljus* (ref. 1), 39–41, 71–72; Nilsson, interview (ref. 1).

24. Gösta Brogren and Per-Olof Nilsson, "Report on Nordic Conference on Synchrotron Radiation Gothenburg, June 9, 1975" (1975), 1, 2–3, 6, 8, 11.

25. Forkman, *Och det blev ljus* (ref. 1), 74–81. A pulse stretcher is an accelerator concept designed to turn short pulses of electrons into longer, continuous beams. In the case of MAX, these electron beams were to be used for firing on the nuclei of elements to study their properties. Ibid., 55, 74–79.

graduated accelerator physicist from the Royal Institute of Technology in Stockholm, Mikael Eriksson, was recruited.[26] Per-Olof Nilsson, still harboring ambitions to create a Swedish national synchrotron radiation laboratory, contacted Mikael Eriksson upon his arrival in Lund and suggested that the MAX accelerator be modified to also produce synchrotron radiation.[27] By this time, promising results in both the VUV/soft x-rays and hard x-rays regimes had emerged out of the experimental programs with synchrotron radiation at Stanford, Hamburg, Novosibirsk, Wisconsin, and Orsay.[28] Inspired by these successes, in January 1978 the group in Lund submitted a proposal to NFR for a 444 kSEK grant (approx. $80,000) to modify the MAX accelerator. The purpose was explicit: "construction of a Swedish national synchrotron radiation source."[29] The review of the proposal was positive, approving the technical design and commending its cost-effectiveness, and concluding that the Swedish demand for synchrotron radiation in "biology, atomic and molecular physics, photoemission and surface physics" well justified the investment.[30] Due to these favorable assessments, the proposal won the necessary support in the research council and was granted the requested money in 1979.[31] The lukewarm attitude of the 1975 Gothenburg conference improved gradually as Swedish physicists returned from visits to other synchrotron radiation laboratories, finding employment and launching research programs at Swedish universities, primarily in Uppsala, Gothenburg, and Linköping.[32] As a result, a national user base took shape and began to live up to the intention of the 1978 application that the MAX project was to become a national resource. Building on the spectroscopy-related physics and materials science tradition most prominent in Uppsala (that would culminate with Kai Siegbahn's Nobel Prize in 1981), but also in Gothenburg and Linköping, the groups that formed the early user base

26. Eriksson, interview (ref. 1).

27. Nilsson, interview (ref. 1).

28. Winick and Bienenstock, "Synchrotron Radiation Research" (ref. 3), 34.

29. Anonymous, "Rapport från NFR:s arbetsgrupp" (ref. 23), 2; Forkman, *Och det blev ljus* (ref. 1), 100; Karl-Fredrik Berggren, "Ang. Möjligheten att utnyttja MAX som synkrotronljuskälla," (1978), Swedish Natural Science Research Council Report, 1–2.

30. Dirk Husmann, "Comments on the Proposal to Use MAX as a Beam Stretcher and a Synchrotron Radiation Source" (1978), NFR Report, 1, 3; Berggren, "Ang. Möjligheten" (ref. 29), 10.

31. Forkman, *Och det blev ljus* (ref. 1), 102.

32. Michael Hart, Christof Kunz, Sergio Tazzari, and Bengt Nordén, "International Evaluation of the MAX II Project January 1990: Report to the Research Council by an International Group of Experts" (1990), Swedish Natural Science Research Council Report, 5; Anders Flodström, interview by author, Stockholm, 22 Mar 2007; Nilsson, interview (ref. 1).

for the MAX project became strong advocates of synchrotron radiation. During the construction of MAX, they conducted experiments at facilities abroad, gaining experience and inspiration that they could later invest in MAX-lab, and hence a vibrant user community was already in place when MAX-lab delivered its first radiation in 1986.[33]

By 1982, MAX-lab had made its way into the Swedish governmental budget bill. The government declared full support for the project, and stated the ambition that MAX-lab be developed into a Swedish national research facility. Although the government did not pledge any direct financial support for MAX-lab, the acknowledgment in the budget bill gave the project legitimacy, most notably at LU, where it helped to resolve the question of its organizational status (it became a "special entity," directly under the Office of the Vice-Chancellor) and to settle a local dispute over the location of the laboratory in an empty machine hall at the Lund Institute of Technology.[34] Thus by 1982, the half-built accelerator had found both its physical and organizational home, and construction and commissioning of scientific equipment could begin. The MAX accelerator started operation in March 1985, and hosted its first experimental run with external users in 1986.[35]

The construction and commissioning of MAX and its beamlines was for the most part the small-scale work of a few people, who shared a devotion and enthusiasm for the project and were prepared to put in extra hours and improvise their way out of difficulties. The machine director Mikael Eriksson, the first coordinator for synchrotron radiation research Anders Flodström, and Per-Olof Nilsson, who became the unifying force of the national user community, are named as especially important in bringing MAX-lab into being. MAX was a "homemade" accelerator, constructed in a step-by-step fashion and with no overarching schedule or budget determined from start to end.[36] The constantly changing financial situation often made the whole project uncertain, but work continued: "For some reason, we were a few very enduring people, and finally it started to rotate."[37]

33. Nils Mårtensson, interview by author, Lund, 7 Nov 2006; Leif Johansson, interview by author, Linköping, 25 Aug 2006; Flodström, interview (ref. 32), Nilsson, interview (ref. 1); Forkman, *Och det blev ljus* (ref. 1), 112–113.

34. Forkman, *Och det blev ljus* (ref. 1), 106–14.

35. Ibid., p. 134; Anonymous, "Background Material for the Evaluation of the Swedish National Facilities 2002" (2002), MAX-lab Report to VR, 2:4.

36. Forkman, *Och det blev ljus* (ref. 1), 116, 129–30; Mikael Eriksson, interview by author, Lund, 28 Mar 2007; Flodström, interview (ref. 32).

37. Eriksson, interview (ref. 1).

A comparison can be made with a contemporaneous project to build a synchrotron radiation facility in the United States, at Brookhaven National Laboratory. The National Synchrotron Light Source (NSLS) was the first comprehensive attempt within the United States Department of Energy's (DOE) national laboratory system to establish a synchrotron radiation facility (the Stanford Synchrotron Radiation Laboratory, SSRL, was not purpose-built and became a DOE facility only after four years of operation) and was first conceived in 1970. The NSLS project consisted of two accelerators, one for VUV and soft x-rays and one for hard x-rays; thus, technically, the MAX accelerator was very similar to the VUV/soft x-ray machine of the NSLS. The magnet lattice of MAX was even modeled partly on the NSLS machine (for comparison, see Table 1).[38] As simultaneous projects—funding for NSLS commenced in 1978—the similarities and the striking differences between the two are interesting and informative for understanding the MAX-lab case. Though retrospectively described as an "arduous" and "traumatic" experience, the NSLS was a facility planned, designed, constructed, and, not least of all, funded within the solid organizational and infrastructural context of the DOE and Brookhaven National Laboratory.[39] The NSLS and MAX projects are similarly described by the people involved. Both were designed and built by teams working after-hours, with allegedly very insecure funding conditions, delays, and constant threats to the survival of their respective projects.[40] But while the NSLS had a budget of $24 million from the Energy Research and Development Administration (ERDA, later the DOE) right from the start, the MAX project was funded through sixteen different grants and in-kind contributions from six different funding bodies and agencies over ten years, of which the direct grants in total amounted to 9.4 million SEK (approx. $1.5 million), and all of which were sought through separate applications or requests from the MAX group.[41] The institutional contexts of the two projects were also radically

38. Eriksson, "Accelerator System MAX" (ref. 1), 335.

39. Robert P. Crease, "The National Synchrotron Light Source, Part I: Bright Idea," *Physics in Perspective* 10 (2008): 438–67, on 439.

40. Robert P. Crease, "The National Synchrotron Light Source, Part II: The Bakeout," *Physics in Perspective* 11 (2009): 15–45; Eriksson, interview (ref. 1); Flodström, interview (ref. 32).

41. In chronological order, they were as follows: 2.4 MSEK from the Atomic Science Research Council (AFR), 750 kSEK from the Knut and Alice Wallenberg Foundation (KAW), 600 kSEK from the Anniversary Foundation of the National Central Bank of Sweden (RJ), and 150 kSEK from LU, for the nuclear physics program, including MAX construction, in 1976; 700 kSEK from KAW for the nuclear physics program, including MAX construction, in 1980; 390 kSEK from NFR, for the synchrotron radiation program at MAX, in 1980; an assistant professorship funded

TABLE 1. MAX I Compared to Other Contemporary Storage Rings for Synchrotron Radiation

	MAX I	*NSLS (VUV/ soft x-ray ring), Brookhaven*	*Aladdin, Madison, Wisconsin*	*HESYRL, Hefei, China*	*BESSY, Berlin*
Start of construction	1976	1978	1977	1981	1979
Start of user operation	1987	1982	1980	1987	1981
Maximum energy (MeV)	550	750	1000	800	800
Injection energy (MeV)	100	n/a	100	240	n/a
Circumference (m)	31.8	51.02	88.9	65.8	62.4

Source: Eriksson, "The Accelerator System MAX" (ref. 1); Bao Zhong-mou and Xia Zhong-ling, "The Hefei Synchrotron Radiation Laboratory (HESYRL): An 800 MeV Electron Storage Ring and its Synchrotron Radiation Experiment Area," *NIM* 208 (1983): 19–22; J. S. Worgan, "The Status of the SRS Facility," *NIM* 195 (1982): 49–57; W. Peatman, "The First Year of User Operation at BESSY," *NIMPR* 222 (1984): 6–8; Ednor M. Rowe and Pamela Woodruff, "Status of the Synchrotron Radiation Center of the University of Wisconsin, Madison," *NIM* 172 (1980): 9–12.

different; whereas the NSLS was built at Brookhaven National Laboratory, an "ideal place" for a synchrotron radiation laboratory, "given its interdisciplinary resources, superb accelerator building, and history of supporting facilities for outside users," the MAX project was little more than an ordinary research project at a university department, built in the basement and moved to a refurbished warehouse after a few years.[42] The differences between Brookhaven—situated in a system of National Laboratories under a federal supervising agency—and the local university environment in Lund thus make the NSLS and MAX-lab projects almost impossible to compare.

by LU for synchrotron radiation research, in 1980; housing including conventional facilities such as electricity and building maintenance, from LU, in 1981; 600 kSEK from FRN and 420 kSEK from KAW for accelerator construction, in 1982; and 3.4 MSEK for beamlines and experimental equipment (six individual grants), from FRN, in 1983–1988. Forkman, *Och det blev ljus* (ref. 1), 80–81, 89, 102, 111–12, 115, 129. KAW is a Swedish private foundation whose purpose is to "promote scientific research and education for the gain of the country." Since its founding in 1917, it has distributed 10.8 billion SEK (approx. $1.5 billion) in grants, primarily for university-based science and education. Anonymous, "Knut och Alice Wallenbergs Stiftelse: Verksamheten 2006" (2007), KAW Annual Report, 2. RJ is a private foundation funding predominantly social science research but also, occasionally, projects in natural science. Anonymous, "Stiftelsen Riksbankens Jubileumsfond: Årsberättelse 2008" (2009), RJ Annual Report, 9–10.

42. Crease, "Part I" (ref. 39), 444.

According to sources, the comparatively unfavorable conditions did not prevent MAX from reaching high standards, and commentators agree that although the machine rated below most of its contemporaries on specific performance parameters, the whole experimental setup with storage ring, beamlines, and experimental stations was of the highest standard for some applications.[43] But the organization was very informal, and everything achieved at the lab came about through small-scale initiatives, step-by-step developments, fortuitous circumstances, and the devotion and ingenuity of a small group of people working extra hours—"very far from big science," according to key people.[44] The next MAX project, on the other hand, was significantly larger by almost all accounts.

THE BIG MAX

The Proposal

With MAX, the accelerator physics group in Lund had shown its capacity to design and construct a machine for the benefit of a Swedish national user community, despite uncertainties and suboptimal funding. In the meantime, scientific and political developments had increased the visibility and appraisal of the applications of synchrotron radiation, with new facilities under planning and construction in Europe, the United States, and Japan, and a growing demand for access to state-of-the-art synchrotron radiation facilities in the scientific communities. On the European scene, the collaborative project to create the ESRF had emerged as a realistic future alternative for synchrotron radiation research in both the hard x-ray and the VUV/soft x-ray ranges.

The MAX-lab personnel had already begun work on a new, larger accelerator in 1985, before MAX was taken into operation. They envisioned a Nordic dedicated synchrotron radiation source, called SuperMAX, built around a "technically very advanced" accelerator that would cover the whole spectral range of hard x-rays and VUV/soft x-rays.[45] The SuperMAX proposal was submitted to the Natural Science Research Council in 1986, at about the same time as the

43. Jesper Andersen, interview by author, Lund, 11 Oct 2006; Johansson, interview (ref. 33); Mårtensson, interview (ref. 33).

44. Andersen, interview (ref. 43); Flodström, interview (ref. 32); Nilsson, interview (ref. 1); Eriksson, interview (ref. 1); Eriksson, interview (ref. 36).

45. Forkman, *Och det blev ljus* (ref. 1), 130, 158.

discussion on possible Swedish participation in ESRF was at its most intense. When the decision was reached that Sweden was going to join, it became clear that the ESRF thereby would fill part of the growing demand for synchrotron radiation in the Swedish scientific community, especially those in the hard x-rays regime. The council concluded that SuperMAX was too ambitious, especially given the Swedish commitment to the ESRF. With the future ESRF envisioned primarily as a source of hard x-rays, the research council's policy was that domestic developments in synchrotron radiation should stay in the VUV/ soft x-rays range (also corresponding to the Swedish areas of strength in physics and materials science), and so MAX-lab was told to redirect and lower its ambitions accordingly.[46]

In 1987, MAX-lab returned with a proposal for a smaller, yet advanced and ambitious, accelerator.[47] This proposal met heavy resistance in the council and was turned down, which forced the project group to intensify their efforts to solidify the scientific base. The work of an ad hoc committee at MAX-lab and a 1989 conference with over a hundred scientists from nearly all fields with prospective interest led to the formulation of concrete plans for MAX-lab's future in the early 1990s, as well as the establishment of necessary credibility around these plans, from the existing and potential user community. Suggestions included completion of the equipment of the existing MAX accelerator (by now referred to as MAX I) with nine beamlines by 1992 and the construction of an entirely new, third-generation synchrotron radiation source with emphasis on VUV and soft x-rays applications—the MAX II.[48] In March 1989, the board of LU expressed crucial support for the project, and in August an application for a grant of 40 MSEK (approx. $5.5 million) to cover the construction of the accelerator was submitted to FRN.[49] In the governmental research bill of 1990, the MAX II project was mentioned in a typical way—it received an endorsement, but it was presumed that the research council would

46. Anonymous, "Minnesanteckningar från överläggning i Stockholm 1986-12-03 om nordisk samverkan rörande deltagande i ESRF" (1986), Swedish Natural Science Research Council Meeting Minutes; Forkman, *Och det blev ljus* (ref. 1), 161–62; Eriksson, interview (ref. 36).

47. Indrek Martinson, Bengt Forkman, Mikael Eriksson, and Ralf Nyholm, "Proposal for a 1 GeV Synchrotron Light Source" (1987), MAX-lab Report.

48. Forkman, *Och det blev ljus* (ref. 1), 162–63; Ulf Karlsson, "Activity Report 1989" (1990), MAX-lab Annual Report, 38.

49. Forkman, *Och det blev ljus* (ref. 1), 163–65; Bengt Forkman, "Application to the National Council for Planning and Coordination of Research for a 1.5 GeV Synchrotron Radiation Storage Ring for VUV and Soft X-rays" (1989), MAX-lab Application to FRN.

take the initiative.[50] The international evaluation of late 1989 praised the achievements of the MAX-lab staff on MAX I, but also expressed concerns that MAX-lab apparently proposed to carry over the small-scale style of operation of MAX I to the construction and operation phases of MAX II, which in their opinion required restructuring and enlargement of the organization. The conclusion in the report, however, was that the MAX II design concept was sound and that the project should be made a priority in the council—it was called "an exciting step forward." The appendix to the evaluation report contained letters of intent from researchers in various fields, together with a list of fifty-four interested synchrotron radiation users in the Nordic countries compiled by Per-Olof Nilsson from a questionnaire in March 1989.[51] With this demonstration of support from the potential user community, the MAX II project effectively obtained its scientific go-ahead. The political decision, however, was still pending.

The Political Process

Compared to international commitments such as Sweden's membership in CERN and ESO, the MAX II project was not very big at all.[52] But a domestic commitment, albeit smaller in direct financial terms, is arguably a larger strategic choice for a government or scientific community. It is in principle possible to exit international collaborations, and Sweden's involvement was typically limited to the payment of membership fees and the utilization of a facility by Swedish scientists. MAX II, on the other hand, would be entirely designed, constructed, and built domestically, and a national scientific base would have to be mounted and maintained by strategic priorities in the science policy and funding system to motivate the investment. Furthermore, the MAX II project involved a range of stakeholders from different scientific communities, all of whom had to be convinced that the usefulness of the MAX II facility to their specific discipline would outweigh a likely draining of resources from the ordinary funding of their work.[53]

50. Forkman, *Och det blev ljus* (ref. 1), 168.

51. Hart et al., "International Evaluation MAX II" (ref. 32), 9, 12.

52. At this time, CERN cost more annually for Sweden than the whole direct investment in MAX II was likely to cost (130 MSEK in 1992, approx. $18 million), and the annual contribution to ESO was about half the sum MAX-lab had applied for in 1989 (23 MSEK in 1992, approx. $3 million). Anonymous, "Forskning för Kunskap och Framsteg" (1993), Swedish Governmental Bill 1992/1993:170, 425.

53. The Swedish scientific community had some bad experiences with large projects; CERN II had partially drained resources from other fields in Sweden during the 1970s. Widmalm, "Big Science" (ref. 18), 123, 126.

The major question associated with MAX II in the council was whether sufficient potential users existed to justify the investment and long-term commitment and whether these potential users could be convinced of the broad usefulness of MAX II. Despite the growth of an international user community around synchrotron radiation, and the emergence of large dedicated facilities around the world (for example, the ESRF in Grenoble and its counterparts in the United States and Japan, each of which aimed at annual numbers of users in the thousands rather than hundreds), the usefulness of synchrotron radiation to Swedish science was questioned in the council. A representative of MAX-lab, invited to do a presentation at the council, was "laughed down" when he suggested that the laboratory would have a thousand annual users by the beginning of the 2000s.[54] Biologists and chemists in the council in particular voiced their opposition to the project. Arguing that MAX II was a mere physics project (this was, in a sense, correct—the MAX II funding application had been focused on physics applications), they contended that the council already had paid for enough large-scale physics facilities. Apart from the CERN membership, the Svedberg Laboratory (TSL) in Uppsala and the Manne Siegbahn Institute (MSI) in Stockholm, both for physics research, had privileged status as national laboratories.[55] Uppsala University chemists and biologists argued for the construction of a hard x-ray synchrotron radiation source in Uppsala, while representatives from other universities were of the opinion that the project was too big for Sweden and that the money would be better spent at the ESRF.[56] The reported technological developments indicating that MAX II could be made to also produce hard x-rays (see below) seemed to have been lost in the debate.

The final resolution of the matter was symptomatically Swedish. In May 1990, NFR gave the MAX II project its full support, though not only without pledging any money but in fact recommending that others should pay. Despite the project's relative size and importance, each funding agency acted as if they were processing one of their regular applications for projects. In practice, this meant that while strongly endorsing the project and underlining its importance for Swedish science, the different agencies attempted to hand over the bill to

54. Ingolf Lindau, interview by author, Lund, 29 Jan 2007. In 2000 and 2001, MAX-lab had over 600 annual users. Jesper Andersen, Ulf Johansson, Ralf Nyholm, and Helena Ullman, "Activity Report 2000" (2001), MAX-lab Annual Report; Jesper Andersen, Ulf Johansson, Ralf Nyholm, and Helena Ullman, "Activity Report 2001" (2002), MAX-lab Annual Report.

55. Lars Gidefelt, interview by author, Stockholm 16 Nov 2006.

56. Flodström, interview (ref. 32); Anders Liljas, interview by author, Lund, 10 Nov 2006.

each other or share it without anyone taking overall responsibility. The accelerator, with a projected cost of 40 MSEK, was to be paid by FRN. The new building for the laboratory and the "conventional facilities" (including lab and office space, electricity and water supply, and the like) was to be provided by LU. The beamlines and the experimental equipment were, in the hopes of NFR, to be paid by the Knut and Alice Wallenberg Foundation (KAW), university groups in Nordic countries collaborating on instrument construction at the future MAX-lab, and the Technical Sciences Research Council (Teknikforskningsrådet, TFR). The annual operations budget for MAX-lab—which would increase dramatically with the construction of a whole new accelerator and a number of new instruments—was, in the council's opinion, LU's responsibility to fund, either within its regular budget or by convincing the government to award a special annual grant.[57]

In January 1991, the government made a decision of sorts to go ahead with the project. However, the only money pledged by the government was 62 MSEK (approx. $9 million) for the building; all other construction and operations costs were to be covered out of the existing frameworks of the Swedish National Board of Universities and Colleges (UHÄ), NFR, FRN, and LU. This policy is remarkable, first on behalf of the government who gave the project full support without securing a budget and even without any active attempt to coordinate the funding effort, and second because the government and the councils together pledged over 100 MSEK (approx. $14 million) for the accelerator and the building without securing money for beamlines and experimental equipment or for future operation costs. In effect, this meant that governmental funding was commenced for an accelerator and a building to host it without any guarantee that they would actually be put to use. Beamlines and experimental equipment were later funded by grants from FRN and KAW (see below). Already during construction this distributed funding model caused severe problems for the project and threatened its survival. In 1993 it became clear that the operations costs for the coming year were to exceed the funds made available by the council, and the situation had to be resolved by a bailout of 1 MSEK (approx. $150,000) from LU and 2 MSEK from NFR to keep the activities on MAX I running without jeopardizing MAX II construction.[58]

MAX II was, by design, an optimized VUV/soft x-rays synchrotron radiation source, and at the time of its approval, similar sources specializing in this

57. Forkman, *Och det blev ljus* (ref. 1), 172–77.

58. Ibid., 176, 180, 183, 217.

wavelength spectrum were either in the planning stages or under construction elsewhere in the world to complement the large hard x-ray sources also under way. One predecessor of MAX II, and a comparable source in technical design and scientific ambition, was the Advanced Light Source (ALS) that was built at the Lawrence Berkeley National Laboratory (LBL) in Berkeley, California, in the late 1980s. First conceived in 1982, the ALS was part of the plans at LBL to create a National Center for Advanced Materials (NCAM), including several other experimental facilities apart from the ALS, that would help in establishing a new core mission for the lab, which had formerly been accelerator-based nuclear physics.[59] The ALS project was thus very much about readjusting and redirecting ambitions in an institutional context accustomed to large projects, whereas MAX II was a project of unprecedented size in Sweden and thus required efforts of a size and scope never experienced in its institutional context. The comparison between MAX II and ALS is almost as striking as that between MAX I and NSLS—in institutional, political, and financial respects the differences could hardly have been greater.

The debate within the scientific community and among science policymakers that preceded the realization of ALS is reminiscent of that preceding the go-ahead for MAX II: materials scientists and representatives of other fields "worried that the ALS would rob funding better spent for smaller projects," some arguing that the hard x-ray source APS would be the wisest investment and would undo the need for ALS, just as some Swedish scientists argued that money would be better spent on the ESRF membership than on MAX II.[60] The political process of ALS most differed from that of MAX II in that the lengthy debate eventually resulted in a decision by the U.S. Congress to fund the project in full. It should, of course, be mentioned that such funding decisions by the U.S. Congress are part of the yearly federal budget process and that ALS, just like any other similar project in the United States, therefore only had its funding secured for a year at a time. Hence in this respect, the funding decisions for the MAX projects had more certainty than the NSLS and ALS, despite incoherence and underfunding.[61] The funding profile for MAX II was not unlike that of MAX I—at the time of its opening to external users in 1997, MAX II had been financed through seven different grants from four different

59. Westfall, "Retooling for the Future" (ref. 12), 571, 578–79.

60. Ibid., 584.

61. E.g., Peter J. Westwick, *The National Labs: Science in an American System, 1947–1974* (Cambridge, MA: Harvard University Press, 2003), 94.

TABLE 2. MAX II Compared to Other Contemporary Synchrotron Radiation Sources

	MAX II Lund, Sweden	*ALS* Berkeley, California	*ELETTRA* Trieste, Italy
Start of construction	1991	1987	1991
Start of user operation	1997	1993	1993
Maximum energy (GeV)	1.5	1.9	2
Circumference (m)	90	196.8	259.2

Source: A. L. Robinson and A. S. Schlachter, "The ALS: A Third-Generation Light Source," *NIMPR A* 291 (1990): 499–504; A. Abrami et al., "First Experimental Tests at the New Synchrotron Radiation Facility ELETTRA in Trieste," *NIMPR A* 349 (1994): 609–13; Å. Andersson et al., "The MAX II Synchrotron Radiation Storage Ring," *NIMPR A* 343 (1994): 644–49.

funding sources, totaling 172.1 MSEK (approx. $25 million).[62] The ALS, a somewhat larger project (see Table 2), ended up costing $99.9 million and was funded completely by the federal government.[63] The comparison with ALS, similar to that between MAX I and NSLS, further shows the institutional differences between the U.S. National Laboratory system and the significantly more decentralized and ill-prepared Swedish science policy system, and gives some contextual explanation to the underperformance of Swedish science policy in handling the MAX II project. But it also underscores an argument put forward by some commentators, which will be revisited in the final discussion: It is remarkable that the project was realized at all.

Construction and Operation

MAX II construction presented a whole new challenge to the accelerator group. While MAX I was a piece of "Lundian handicraft," the task of constructing

62. In chronological order, they were as follows: 40 MSEK from FRN for construction of the accelerator in 1990, to be increased to 41.1 MSEK during the coming five years; 62 MSEK from the government for the building in 1991; 1 MSEK from FRN for experimental equipment in 1992; 40 MSEK from KAW for experimental equipment in 1992; 8 MSEK from FRN for experimental equipment in 1993; 5 MSEK from FRN for experimental equipment in 1994; 15 MSEK from FRN for experimental equipment in 1995. Note that no operational costs, either for the existing MAX I or for the new MAX II facility, are included but that these were covered by the ordinary annual grant from the NFR, subject to negotiation every year to cover for increased costs. Forkman, *Och det blev ljus* (ref. 1), 172, 183, 203, 215.

63. Westfall, "Retooling for the Future" (ref. 12), 605, 607.

MAX II was regarded as "one of the most advanced technical undertakings done in Sweden," requiring the accelerator group to "rethink and think in industrial terms."[64] The ambitions "to get a light source that was internationally competitive" as described by the then-director of the laboratory was, according to the 1990 international review of the accelerator concept, met by the design: MAX II would be "superior to most" laboratories in ultraviolet and soft x-rays.[65] Despite occasional financial difficulties, such as the aforementioned troubles of 1993, construction proceeded roughly according to plan. The first three beamlines on MAX II, funded by KAW (see footnote 62), were conceptualized, designed, and built largely by external user groups. As much as it was a strategy on behalf of laboratory management—to make instruments meet the needs of the user community and make the most of the users' specialist knowledge—the extensive involvement of users in design and construction was also due to financial constraints. Grants awarded for instrumentation typically covered only capital investment and not manpower, and the operational budget of the laboratory did not allow for continuous recruitments to fill the needs. Especially the groups from Uppsala, Linköping, and Lund that made up the core scientific base for MAX I were engaged in this work, and once the beamlines were completed, these groups also took responsibility for maintenance and user support.[66] Similar arrangements have been put in place at many synchrotron radiation laboratories elsewhere—for example at both the facilities used for comparison in earlier paragraphs, the NSLS and ALS—but the extent to which the time, talent, and effort of external user groups have been exploited in MAX-lab's case is probably exceptional, as will be discussed in further detail below.

MAX II was inaugurated on September 15, 1995, and the first experimental data with MAX II radiation was collected in May 1997. It is interesting to note, given the facility's clear VUV/soft x-rays focus, that the first result obtained was the mapping of a protein on a beamline utilizing hard x-ray radiation.[67] Researchers in life sciences had been involved in the planning work for MAX II in the late 1980s, because speculation held that technical advances could make possible the extraction of hard x-rays from the ring. The speculation was subsequently matched by a technical solution that was implemented during

64. Forkman, *Och det blev ljus* (ref. 1), 116, 213.

65. Lindau, interview (ref. 54); Hart et al., "International Evaluation" (ref. 32), 8.

66. Ralf Nyholm, interview by author, Lund, 4 Oct 2006.

67. Liljas, interview (ref. 56); Jesper Andersen, Ralf Nyholm, Monica Olofsson, and Stacey Sorensen, "Activity Report 1996" (1997), MAX-lab Annual Report.

MAX II construction and that contributed to the closing of the gap between VUV/soft x-rays and hard x-rays in the 1990s, creating the opportunity for MAX-lab and several other synchrotron radiation laboratories that had focused entirely on VUV and soft x-rays to expand their ambitions into several scientific areas previously excluded.[68] A small group already had been created at MAX-lab at the time of the MAX II funding decisions, with involvement from LU biologists and chemists, to plan and construct a beamline utilizing hard x-rays.[69] In order to get on track as soon as possible, the group bought the blueprints of an existing beamline at another laboratory and constructed an exact copy, which hence could start operation in May 1997.[70] The beamline became a success, at least in absolute numbers, accounting for over a third of the MAX-lab users in 2002.[71] Showing that MAX II could produce hard x-rays, the activities at the beamline triggered a larger demand and the construction of additional hard x-rays beamlines at MAX-lab, with financial involvement from pharmaceutical companies AstraZeneca and NovoNordisk as well as the Danish Biotechnological Instrument Centre (DABIC) (and additional funding from KAW).[72] While these beamlines reportedly performed below the standards of counterparts at other sources (for example, the ESRF), the smaller travel distances, the availability, and the apparent flexibility on behalf of the scientific personnel created a certain demand from Swedish and Danish scientists both in academia and industry.[73]

Interestingly, despite the relative success of the hard x-rays beamlines at MAX-lab and the fact that approximately a third of the users at MAX-lab identify as life sciences researchers, the hard x-rays activities are frequently referred to as "an island" at MAX-lab and are considered by many to be external to the laboratory's core mission and identity.[74] The possible reasons are many. As mentioned, the scientific base in Sweden that motivated the MAX II investment was mainly the strong physics and materials science traditions in

68. Hart et al., "International Evaluation" (ref. 32), 7; Eriksson, interview (ref. 36).

69. Liljas, interview (ref. 56).

70. Yngve Cerenius, interview by author, Lund, 10 Oct 2006.

71. "Over 200" out of a total of 589. Anonymous, "Background Material" (ref. 35), 2:5.

72. Nilsson, interview (ref. 1); Liljas, interview (ref. 56); Ralf Nyholm, interview by author, 18 Sep 2008.

73. Cerenius, interview (ref. 70); Thomas Ursby, interview by author, Lund, 20 Oct 2006.

74. 199 out of 580 in 2004 and 165 out of 572 in 2005. Users choose among physics, chemistry, and life sciences when registering for beamtime. Ralf Nyholm, e-mail correspondence with author, 30 Mar 2006; Cerenius, interview (ref. 70); Eriksson, interview (ref. 36); Ursby, interview (ref. 73); Nyholm, interview (ref. 72); Börje Johansson, interview by author, Uppsala, 12 Oct 2006.

Uppsala, Linköping, and Gothenburg, and it was a deliberate choice by science policymakers in the early 1990s to allow the membership in ESRF to guarantee supply of hard x-rays to Swedish researchers and make MAX-lab entirely a VUV/soft x-rays lab. Parallel with the opportunities opened in the hard x-rays regime, the ordinary process of constructing and commissioning the long-anticipated and awaited beamlines for VUV/soft x-ray spectroscopy at MAX II took place, in collaboration with the most prominent MAX I users. These groups, primarily physicists from Uppsala and Linköping, became an influential core MAX II user base and they soon populated the MAX II scientific committees.[75] All of this gave the VUV/soft x-rays activities a prominent position and created a symbiosis between MAX-lab and its constituent user groups in Swedish physics, especially the Uppsala physics department whose entire curriculum is directed toward the use of synchrotron radiation (with the exception of a theory group).[76] In 2007, MAX-lab commissioned a smaller ring, the MAX III, specializing in VUV and soft x-rays. Viewed from an international perspective, this is an unusual priority (most labs move further in the hard x-rays direction), but has been lauded by an international review because it is seen to solidify the Swedish user base and benefit its areas of strength.[77]

The above-described scientific development of MAX-lab since the go-ahead decision for MAX II in 1991 has transformed the laboratory from a small and specialized VUV/soft x-ray lab to a full-fledged synchrotron radiation facility with a battery of experimental facilities covering the whole spectrum of possible fields of utility of synchrotron radiation. Meanwhile, the core activities in physics and materials science that were the original raison d'être for the laboratory have only been strengthened. The annual number of users has grown steadily, from approximately 100 in 1987 to 600 in 2007 and doubling (from about 200 to over 400) in the years of MAX II construction, i.e., 1992–1997.[78]

75. Nyholm, interview (ref. 72).

76. Joseph Nordgren, interview by author, Uppsala, 13 Oct 2006; Anne Borg, Yvan Bruynseraede, Talat S. Rahman, Cyrus R. Safinya, Hiroyuki Sakaki, D. Phil Woodruff, Mats Larsson, and Joakim Amorim, "Evaluation of the Swedish Condensed Matter Physics, 2004" (2005), VR Report 12:2005, 27–28.

77. Samuel H. Aronson, Robert L. Jaffe, Malcolm S. Longair, Irene Nenner, Jochen R. Schneider, and Gunnar Öquist, "Review of the Swedish National Facilities 2002" (2002), VR Report 2002:6, 43.

78. Exact figures are not available, due to occasional changes over the years of the routines for registering users as well as changes of periods covered by the Activity Reports from calendar year to academic year (fall–spring) and back. These approximate figures are reported in the official history of MAX-lab. Forkman, *Och det blev ljus* (ref. 1), 20, 250.

It is clear that MAX II has made MAX-lab known outside the Lund and Uppsala physics departments, strengthened the support for the facility among several different elements of the Swedish scientific community, and turned it into a user facility for the broad community of Swedish natural sciences.[79] However, the lack of comprehensive funding from the start, and the continuous need to find external funding for every project in the buildup to the present-day laboratory, has left marks on the organization that reflect the special nature of the Swedish science policy system.

POLITICAL AND INSTITUTIONAL PECULIARITIES

The Funding Situation

In 1981, when MAX-lab was designated a "National Research Facility" by the NFR, the label meant nothing beyond the mere recognition that the facility was to be available to researchers anywhere in Sweden. Throughout the 1980s, the opinion was occasionally put forth in the council that both MAX-lab and the other national facility, TSL in Uppsala, lacked strategy and coherence and that this was inappropriate for facilities designated as "national."[80] In 1992, a governmental investigation concluded that the funding for the facilities was both insufficient and inconsistent: capital investment came from several different sources (the government, FRN, and KAW); operational costs were covered by a special line item within the governmental floor funding to the host universities; hardly any efforts of coordination were made between the funding sources; and comprehensive overview of de facto overall costs was almost impossible. This situation made responsibility for operations, long-term development, strategic planning, and quality assessment too vague and divided among too many authorities, and the investigation suggested that responsibility for operations be transferred to NFR and that a special annual grant from the government to the council should cover for operations, "separate from the other grants to the research councils" but with priorities between the facilities

79. Jens Fenstad, Olle Edqvist, Ove Poulsen, and Kåre Jansson, "International Evaluation of Swedish National Facilities: April 1997" (1997), NFR Report, 27; Aronson et al., "Review 2002" (ref. 77), 12; Eriksson, interview (ref. 36); Johansson, interview (ref. 74); Nyholm, interview (ref. 72); Peter Honeth, interview by author, Lund, 9 Jun 2006; Nils Mårtensson, interview by author, Lund, 29 Mar 2006; Maria Novella Piancastelli, interview by author, Uppsala, 13 Oct 2006.

80. Forkman, *Och det blev ljus* (ref. 1), 112, 184–85.

made within the council.[81] A 1993 governmental bill implemented a modified version of this suggestion by transferring the financial responsibility for operation of the national facilities to NFR, but without any grant to cover the operation, instead stating that the costs should be "weighed against" other expenses. The bill therefore largely reinforced and institutionalized an existing policy: Investments in research infrastructure—including the national facilities—were to be made within the existing framework of governmental research financing and within the ordinary budget of the council.[82] In the meantime, two additional facilities had been given status as National Research Facilities: the Supercomputer Center in Linköping (in 1989) and OSO in Gothenburg (in 1990), and in 1993 a follow-up investigation was charged with the task of assessing the resource needs of the national facilities.[83] No concrete figures or recommended levels of funding were issued in the investigative report, but rather a number of criteria for receiving "good support" from the council were outlined, including maintaining activities in the international forefront and utilization by researchers from several Swedish universities and not solely the host university.[84]

On the basis of these criteria, the national facilities have undergone reviews every few years. A review in 1997 gave all four facilities a very good appraisal; judged by their scientific achievements, they were all excellent hosts of world-class activities in their respective fields, but they were also expensive and continuously facing organizational challenges in their expansion and development.[85] A 2002 review repeated most of the praise, but it also emphasized the organizational and financial problems at the labs. Once more, the distributed funding model and the lack of financial coordination were identified as the roots of the problem. The report especially pointed out the existence of "shadow economies" (to be discussed later) at the labs that had evolved to counter insufficiencies and incoherence in the ordinary economies, and this problem was identified as particularly significant at MAX-lab. Simultaneously,

81. Ingvar Lindgren, "Nationella Forskningsanläggningar och Nationella Forskningsresurser" (1992), UHÄ Report 1992:5, 3, 5, 9–11, 13.

82. Forkman, *Och det blev ljus* (ref. 1), 186.

83. Lindgren, "Nationella Forskningsanläggningar" (ref. 81), appendix 1, p. 1. Later, the Supercomputer Center was stripped of its status in favor of MSI. Aronson et al., "Review 2002" (ref. 77).

84. Anonymous, "Resursbehov m m för Nationella Forskningsanläggningar och Nationella Forskningsresurser" (1993), NFR Report, 3–4.

85. Fenstad et al., "International Evaluation" (ref. 79), 7, 11, 16, 23.

however, the scientific achievements at MAX-lab were highly praised by the report: The active involvement of users in the facility's development, the ability of the MAX-lab management to run a diverse and constantly evolving research facility and balance the interests of different user groups, and the good relationship with LU were mentioned as important factors for success. The conclusion of the report was clear: In order not to fall back, both MAX-lab and the council had to adjust priorities and strengthen initiatives, and the recommendation was that funding be concentrated toward MAX-lab and OSO, with MAX-lab as the highest priority, if necessary at the expense of the two other facilities.[86] In September 2002, following this recommendation, the research council decided to phase out funding for TSL and MSI in favor of MAX-lab and OSO. One immediate effect was an increase to MAX-lab's annual operations budget of more than 10 MSEK (approx. $1.5 million), but the organizational and financial ambiguities were not changed.[87] The council still exercises very little hands-on governance of the national facilities and does not view it as their responsibility to correct organizational imperfections at the labs, with reference to a general principle of VR to award grants with no specific instruction other than to make the best of it and report back a few years later.[88]

Despite the 2005 establishment of KFI within the council, acknowledging the importance of research infrastructure and elevating its standing within the council, investments in research infrastructure and operations of national facilities are still contained in the ordinary council budget.[89] Attempted prioritization of any of the national facilities would thus unavoidably be subject to the ordinary competition for funds within the council structure. The otherwise opaque and complicated organizational and financial status of MAX-lab (and, to some extent, OSO) and the lack of coordination among different funders has contributed to constant underfunding, mainly because the operating budget from the council has never been balanced with investments, expansion, and number of users.[90] Thereby the willingness or eagerness of the council to support good science—which is their chief mission—has led to the paradoxical situation of a constant lack of sufficient resources for the operation of MAX-lab.

86. Aronson et al., "Review 2002" (ref. 77), 12–13, 15–17, 28, 39, 44, 63.

87. Anonymous, "Årsredovisning 2002" (2003), VR Annual Report, 7, 28; Leif Eriksson, interview by author, Stockholm, 23 Mar 2007.

88. Karlsson, interview (ref. 22); Gidefelt, interview (ref. 55).

89. Anonymous, "Vetenskapsrådets forskningsstrategi 2009-2012" (2007), VR Report 7:2007, 1; Karlsson, interview (ref. 22).

90. Eriksson, interview (ref. 87).

This problem is allegedly acknowledged in the council, but as noted, it is not perceived as being part of the council responsibilities to resolve it. Some long-time MAX-lab users argue that there is a detectable pattern in this: Although the political motive for investment in research infrastructure is that it supposedly benefits the work of Swedish scientists, such investments are regularly made without securing either long-term funding for maintenance and user support, or grants for Swedish researchers to make adequate use of the infrastructures (see further below). "We fool them, we pretend that it doesn't cost that much. The first shot is for free."[91]

The (Dis)organization

The aforementioned "shadow economies," identified in the 2002 review of the national facilities, are essentially MAX-lab's means of coping with underfunding. Important tasks associated with the construction and maintenance of instruments, as well as user support on some beamlines, have been outsourced to external research groups, and several in-house scientists have a listed employment affiliation other than MAX-lab, which suggests that they are paid with money outside of the MAX-lab operational budget.[92] According to the MAX-lab director, the funding shortage is most obvious in the area of user support—it is not uncommon at larger facilities abroad to have three persons working full-time on each beamline, while beamlines at MAX-lab are normally run by one.[93] Some users are concerned that instruments are not kept in adequate shape due to insufficient maintenance.[94] The 2002 facility review noted the inefficient user support and the unsatisfactory situation for beamline scientists, stating that "it would be good for the laboratory if the leading scientists in charge could find more time for their own research, for teaching at their university and for strategic planning of the future of the laboratory and of synchrotron radiation research in Sweden as a whole."[95]

The laboratory organization has been built up gradually as MAX-lab has grown from a small-scale university project to an international user facility, and

91. Quote from Nordgren, interview (ref. 76); confirmed by Roger Uhrberg, interview by author, Linköping, 25 Aug 2006; Johansson, interview (ref. 74); Johansson, interview (ref. 33).

92. Ulf Johansson, Annika Nyberg, Ralf Nyholm, and Helena Ullman, "Activity Report 2008" (2009), MAX-lab Annual Report, 5–6.

93. Mårtensson, interview (ref. 79).

94. Nordgren, interview (ref. 76).

95. Aronson et al., "Review 2002" (ref. 77), 39.

at no point in this process has any comprehensive organizational overhaul been made to meet the new demands of a growing user community and a technically more sophisticated laboratory.[96] Although the operating budget as well as annual capital investment has increased gradually and allowed for some renewal and incremental additions in the staff and the procedures, no complete assessment of the financial needs of the lab has ever been made. Some claim that the MAX-lab management and staff have had their hands full taking care of the growing instruments collection and user community, and thus have not had the opportunity to look in the rearview mirror or to stop and think.[97] As noted and criticized by several reviewers, this has created an opaque organizational structure that still seems to be in place.[98]

The dual organizational status of national facility and university department is peculiar in some of its details. MAX-lab is an extraordinary entity for a university, because of its large number of external users and demand for specialized skills of technical maintenance, and consequently it has been designated a Special Entity positioned outside the ordinary organizational structure of the university and directly subordinate to the Office of the Vice-Chancellor. Parts of MAX-lab are, however, also within the regular university structure, because only a portion of the personnel costs is covered by the annual research council funding and because several positions at MAX-lab are also academic chairs. The university acts as the employer for all laboratory personnel, and the staff with academic positions are formally tied to the Faculty of Natural Sciences.[99] The laboratory director is paid by the council grant, as is one research coordinator position, divided among the three areas: synchrotron radiation, nuclear physics, and accelerator physics. The machine director and deputy MAX-lab director is professor of accelerator physics at the LU physics department and is thus employed entirely by the university. A professorship in synchrotron radiation instrumentation was established in 1997 and is a regular faculty position within the university, but in practice it is a MAX-lab position.[100] These

96. Andersen, interview (ref. 43).

97. Lindau, interview (ref. 54); Nordgren, interview (ref. 76); Mats Fahlman, interview by author, Linköping, 24 Aug 2006.

98. Eriksson, interview (ref. 87); Fenstad et al., "International Evaluation 1997" (ref. 79), 8; Aronson et al., "Review 2002" (ref. 77), 40, 46; Maria Arménia Carrondo, Giorgio Margaritondo, Örjan Skeppstedt, and Tove Andersson, "Report from the Review of the MAX laboratory" (2010), VR Report 5:2010, 21–22.

99. Aronson et al., "Review 2002" (ref. 77), 7.

100. Nyholm, interview (ref. 72); Helena Ullman, interview by author, Lund, 20 Jun 2007; Johansson et al., "Activity Report 2008" (ref. 92), 3–4.

are only a few examples of the creativity with which MAX-lab, LU, and the research council(s) have coped with the distributed and suboptimal funding of the facility.

There are, however, signs that MAX-lab is perhaps not only coping with the unfavorable situation but to a degree has managed to turn it into an advantage—for example, the scientific performance of the laboratory is repeatedly praised in investigations despite the financial situation. Learning to operate under budget constraints may foster an inventive atmosphere and can-do spirit, and both personnel and users claim that the constant lack of adequate resources and the accompanying struggle to survive has forced effectiveness upon every part of the organization.[101] It has allegedly imposed flexibility and an atmosphere of understanding and agreement among the council, the university, and the users; one review even calls it a "unique" model for collaboration between council and university and for the long-term planning for the facility.[102] MAX-lab personnel claim that the organizational fluidity has created a nonbureaucratic organization with informal decision-making and communication channels, causing people to focus less on work descriptions and more on getting things done and solving urgent problems. This has ensured across-the-board collaboration among professional groups and disciplines, and it has helped personnel develop a broader, more complete set of skills, which in the long run has become a competitive advantage for MAX-lab because the laboratory thereby has been technically "optimized as a whole."[103]

It is also claimed (by the interviewees in the following footnote) that the resource scarcity has created especially good relationships between the laboratory and its user community. Forced to hand over responsibility for instruments and user operation to external users, the laboratory management has invited them to participate in and contribute to long- and short-term planning, which has established support for the lab among the scientific communities and made it national in a real sense.[104] This special relation between lab and user community dates back to the late 1970s and the initial ambitions to develop the future MAX-lab facility into a national resource, when the potential user

101. Andersen, interview (ref. 43); Cerenius, interview (ref. 70); Eriksson, interview (ref. 1); Eriksson, interview (ref. 36), Johansson, interview (ref. 33); Uhrberg, interview (ref. 91); Ursby, interview (ref. 73).

102. Aronson et al., "Review 2002" (ref. 77), 11.

103. Andersen, interview (ref. 43); Cerenius, interview (ref. 70); Ursby, interview (ref. 73).

104. Mårtensson, interview (ref. 79), Novella Piancastelli, interview (ref. 79); Eriksson, interview (ref. 36).

community was small and could be extensively involved in planning.[105] MAX-lab management and staff are very careful to emphasize the importance of the user community; it is "the core of the laboratory" and the user involvement is said to make "the process of forming the visions much more advanced."[106] The direct involvement of user groups in design and construction of instruments, as well as operation and user support, has of course helped in creating this fruitful relationship between the lab and its user community.[107] But the buy-in of user groups in the laboratory has its potential drawbacks—foremost when formalized in Participating Research Team (PRT) agreements.

Informal PRTs had already existed at MAX I, where it was customary for the head applicant of grants that paid for an instrument to assume chief responsibility for its operation and maintenance. When MAX II construction started, it became clear that the grants for beamline construction (from KAW, see above) would not cover long-term maintenance and user support, and it was acknowledged that the real competence to design and build beamlines lay with user groups outside the lab organization. Therefore, formal PRT contracts were set up for two of the beamlines, between MAX-lab and groups from Uppsala and Lund, with some involvement from Linköping University.[108] By these agreements, the groups in question are entitled to 75% of the total experimental time available on a beamline, in return for which they are entirely responsible for all maintenance and user support.[109] The contracts, however, seem to have little concrete importance, and the real terms of the PRT arrangements are rather informal and seemingly based on mutual trust. Both PRT heads are unaware of the exact terms of the agreements, and say that they have never seen, let alone signed, any contracts.[110] Although the other beamlines at MAX II have been designed and built by user groups who have also taken responsibility for maintenance and user support, no PRT contracts exist for them, and instead these groups are said to receive a certain priority in the ordinary allocation of experimental time.[111] Seventy-five percent of the experimental time on a beamline seems to be a generous reward for a research group, but one PRT

105. Forkman, *Och det blev ljus* (ref. 1), 102; Eriksson, interview (ref. 36).

106. Anonymous, "Background Material" (ref. 35), 4:1; Flodström, interview (ref. 32).

107. Mårtensson, interview (ref. 79); Novella Piancastelli, interview (ref. 79); Aronson et al., "Review 2002" (ref. 77), 37.

108. Lindau, interview (ref. 54).

109. Nyholm, interview (ref. 72).

110. Andersen, interview (ref. 43); Novella Piancastelli, interview (ref. 79).

111. Nyholm, interview (ref. 72).

member asserts that the workload associated with maintaining a beamline as a good user facility is unreasonable for a single group, and that although the group possesses the knowledge and competence, their time should go to research instead of maintenance of instruments.[112] Criticism has also been voiced in the user community, mainly over the PRT system's lack of transparency.[113]

Neither the extensive involvement of user groups in design and construction of beamlines nor the PRT arrangements are unique when compared to various situations outside of Sweden, but the degree to which they have been institutionalized at MAX-lab, as a means to compensate for funding shortages, is exceptional. The duality of the situation is interesting. Though it is provoked by the insufficient and incoherent funding model and likely adds to the general organizational ambiguities, the user involvement and the PRTs have arguably had the positive effect of deepened and strengthened relationship between MAX-lab and the Swedish scientific community.

DISCUSSION AND CONCLUSIONS

Reasons for MAX-lab's Existence and Success

MAX-lab started as a small-scale university project. Today it is an internationally competitive synchrotron radiation facility with a large user community in a broad range of sciences. It has evolved to its present status through small steps and incremental additions, almost entirely bottom-up and with very little initiative from policymakers. Although MAX II, the largest single step in MAX-lab's development, was a several-million-dollar project, there was never a point when the project was approved by the government or granted a sum of money to provide for its construction. With the exception of one governmental grant for the building, one grant for the accelerator from FRN, and one grant for a few beamlines and experimental stations from KAW, all investments in MAX-lab have been made on the basis of discrete project grants from the research councils and other science funding agencies, all obtained through applications and competition within the framework of ordinary Swedish small-scale research funding.

112. Nordgren, interview (ref. 76).

113. Fahlman, interview (ref. 97); Stacey Sörensen, interview by author, Lund, Sweden, 3 Oct 2006.

Funding a national facility project in this patchy manner is unusual when viewed from an international perspective. The comparisons made in earlier sections, with the NSLS at Brookhaven and the ALS at Berkeley, show that while these labs also had apparent difficulties with regard to underfunding, inexperience, and tortuous political debate and negotiation, they did at some point arrive at funding decisions and were pledged sums of money from the government that were intended to provide for the entire laboratory setup, including operations budgets.[114] Moreover, they were conceived, designed, built, and brought into operation within a well-organized, coherent system of policymakers and science administrators, accelerator constructors and instrument developers, potential users, and representatives from relevant scientific communities. This system, perhaps most significantly at the Berkeley and Brookhaven labs where large-scale facilities had been planned, built, and operated for several decades already, was used to or even designed to handle large-scale projects and employ the appropriate "aggregation mechanisms." MAX-lab came into being in a system of almost opposite character, with no similar "shoulders of giants," no experience of domestic initiatives on this scale, and with an institutionalized inability to make strategic decisions in favor of single projects. This makes its very existence seem improbable.

What, then, made MAX-lab a reality, despite unfavorable conditions? It is perhaps not surprising that commentators, who are also central actors in the story, are united in their claims that it was the work of ingenious and hardworking individuals who overcame the systemic insufficiencies. These stories of heroism, however, are often accompanied by somewhat more analytic assertions that the procedure of small steps, caution, and prudence, and the lack of grandiose plans, were equally important in keeping MAX-lab alive and making it grow despite potential resistance and institutional inadequacies.[115] There is merit and substance to these claims, and they may lead to the conclusion that ingenuity and caution on behalf of individual actors in the system can be sufficient to compensate for a lack of institutional mechanisms in the long run. But the scientific and technological aspects must not be neglected. First of all, unlike some other forms of big science, synchrotron radiation laboratories can

114. Crease, "Part 1" (ref. 39), 439; Crease, "Part 2" (ref. 40), 16–18; Westfall, "Retooling for the Future" (ref. 12), 594–601.

115. Forkman, *Och det blev ljus* (ref. 1); Eriksson, interview (ref. 1); Eriksson, interview (ref. 36); Flodström, interview (ref. 32); Nilsson, interview (ref. 1); Gidefelt, interview (ref. 55); Andersen, interview (ref. 43); Lindau, interview (ref. 54); Mårtensson, interview (ref. 33); Mårtensson, interview (ref. 79); Nordgren, interview (ref. 76).

be built from the bottom up, in small steps and incremental additions, and this is a fundamental prerequisite for the case in question. Second, MAX-lab also had "shoulders of giants" to stand on—a strong accelerator physics group in Lund, with experience dating back to the early 1960s, and the physics and materials science tradition, foremost in Uppsala with its spectroscopy instrumentation group and Nobel laureate Kai Siegbahn.[116] The group of accelerator physicists developed innovative solutions and established good contacts with local manufacturing industry, thereby cutting costs and arriving at technically very advanced accelerator designs that have repeatedly been praised in evaluations. Although direct comparisons are inexact and therefore questionable, and the specific costs for accelerators are not available in the examples used for comparison in previous paragraphs, it is possible to assert that MAX II was an extraordinarily inexpensive accelerator. Its construction costs, covered by the grant from FRN, amounted to 41.5 MSEK (approx. $5.5 million), compared to the ALS that had a total budget of $99.9 million, in which certainly a dozen beamlines were included, but not buildings. The assessments of repeated evaluations underscore the comparison; MAX-lab's accelerators are judged very cost-effective and its designers and constructors are called "truly imaginative."[117]

Key to MAX-lab's achievements is the cross-fertilization of the accomplishments of the accelerator physics group with the strong Swedish tradition in solid-state physics and materials science, from which a user base emerged deeply involved in the development of the laboratory through their capabilities in instrument-building. Already in the late 1970s, when postdocs returned to Uppsala, Linköping, and Gothenburg from stays at synchrotron radiation laboratories in Stanford, Wisconsin, Hamburg, and Orsay, groups were formed that defined and developed their activities in symbiosis with the opportunities emerging at MAX-lab.[118] The small-scale, informal, and academic organization and atmosphere at the laboratory is said to have promoted close collaboration and exchange between accelerator constructors on one hand and scientists and prospective users on the other, making possible an optimization of the performance of the laboratory as a whole despite funding shortages and reliance on ad hoc solutions.[119] Somewhat paradoxically, it seems the healthy involvement

116. Mårtensson, interview (ref. 79).

117. Carlo Bocchetta, Massimo Cornacchia, Leonid Rivkin, Örjan Skeppstedt, and Per Karlsson, "An International Evaluation of the MAX IV Technical Concept" (2006), VR 5:2006, 11; Aronson et al., "Review 2002" (ref. 77), 13.

118. Johansson, interview (ref. 33); Mårtensson, interview (ref. 79); Uhrberg, interview (ref. 91).

119. Andersen, interview (ref. 43); Lindau, interview (ref. 54); Mårtensson, interview (ref. 79).

of users in the planning and operation of the facility was only increased by the inability of the government or the research councils to fund the MAX II project in full, which forced MAX-lab to apply for separate grants for instrumentation together with user groups, who thereby became involved as central contributors to the scientific and technical development.

None of this, however, would have mattered if the political system had been entirely inhibitive or impossible to navigate. While the first MAX was small enough to be kept within LU and survive on fairly modest grants from the research council (in the hundred thousands rather than millions range), the MAX II project unavoidably became a matter for national politics. It could thus, given the institutional preconditions and the total lack of precedent in the science policy system, have been killed before coming close to decision-making level. Here the entrepreneurial efforts of the lab's key individuals emerge as important in the recollections of former lab directors, users, and science policymakers, as well as the work of "MAX-lab friends" in the research council organization and the lobbying efforts of influential academic leaders on the local level who allegedly identified the potential of the project.[120] The support within LU was strong already in the 1980s and grew especially with the MAX II proposal, which received strong endorsements from the central university management.[121] In Sweden's decentralized science policy system, local support of this kind is arguably of vital importance for projects with ambitions beyond the ordinary. What appears to be a fortunate coincidence is that FRN, the funder of the MAX II accelerator and 29 MSEK (approx. $4 million) worth of experimental equipment for MAX II, existed between 1977 and 2001 and most likely made the difference for the realization of the MAX II project, as a "free agent" with an expenditure account of its own, outside the otherwise very discipline-oriented research funding and policy structure. Similarly, it has been emphasized by several commentators that the role of KAW in funding experimental equipment also has been critical to MAX-lab's existence.[122]

120. Lindau, interview (ref. 54); Flodström, interview (ref. 32); Gidefelt, interview (ref. 55); Forkman, *Och det blev ljus* (ref. 1), 161.

121. Forkman, *Och det blev ljus* (ref. 1), 180, 217, 248; Fenstad et al., "International Evaluation 1997" (ref. 79), 8; Aronson et al., "Review 2002" (ref. 77), 17.

122. Anonymous, "The Swedish Research Council's Guide to the Infrastructure. Recommendations on Long-term Research Infrastructures by the Research Councils and Vinnova" (2008), VR Report 5:2008, 21; Forkman, *Och det blev ljus* (ref. 1); Eriksson, interview (ref. 1); Gidefelt, interview (ref. 55), Mårtensson, interview (ref. 79); Nilsson, interview (ref. 1).

The patchy and suboptimal funding model has allegedly had certain indirect advantages, in that it has meant that every instrument project and thereby every addition to the facility has been approved separately through discrete applications and grants. Thus the overall laboratory performance has been subject to continuous evaluation and refinement, and experimental equipment has only been added to the laboratory on the basis of requests by the users, which has improved the potential for effective resource utilization.[123] Key to this of course is the user involvement, mentioned above, based on forced buy-in of external groups and the PRT system. Most prominent among the user groups are the Uppsala University users, mostly in physics but also in some life science applications, whose involvement in MAX-lab has been of utmost importance. This prominence is quantitative—about one-sixth of all users in the years 2000–2005 came from Uppsala University, compared to, for example, one-tenth coming from LU—but also qualitative and historical, as repeatedly mentioned.[124] The importance of the scientific and technical inflow of talent and competence from the physics department in Uppsala, with its internationally leading position in spectroscopy and related instrument construction, is often highlighted in reports and investigations, even sometimes to the degree that MAX-lab is interpreted by and large as a continuation of the strong Uppsala spectroscopy tradition.[125]

Symptomatically Swedish

The Swedish science policy system's lack of institutional mechanisms for promotion of large initiatives and strategic priorities is undoubtedly the underlying reason for MAX-lab's financial and organizational inefficiencies. However, it is the express opinion of several commentators—within the laboratory's ranks, in the user community, and among international evaluators—that MAX-lab also has developed certain unique capabilities and strengths despite the unfavorable conditions, or perhaps because of them.

123. Mårtensson, interview (ref. 33); Mårtensson, interview (ref. 79).

124. Nyholm, interview (ref. 72).

125. Joseph Nordgren, Lars Engwall, Anne-Sofie Gräslund, Per Andersson, Maivor Sjölund, and Marcus Agåker, *Quality and Renewal 2007: An Overall Evaluation of Research at Uppsala University 2006/2007* (Uppsala, Uppsala University: 2007), 280, 282–283; Aronson et al., "Review 2002" (ref. 77), 37; Borg et al., "Evaluation Condensed Matter" (ref. 76), 38–42, 47; Yvan Bruynseraede, Maria Arménia Carrondo, Wolfgang Eberhardt, Michael Grunze, Britt Hedman, Chi-Chang Kao, Lars Kloo, and Per Karlsson, "Scientific Evaluation of the MAX IV Proposal" (2006), VR Report 20:2006, 17.

The inherently dynamic and generic quality of synchrotron radiation laboratories is what ultimately allows a lab like MAX-lab to grow organically and slowly expand its ambitions and capabilities. The expansion into hard x-rays is one example, and in the particular context of MAX-lab, this generic quality made a broadening of the scientific program possible, which undoubtedly strengthened the lab's position in the scientific community and the science policy system. It is an inherent quality of synchrotron radiation facilities that their full spectrum of possible utilizations must not be taken into account at the time of the original investment in a facility, and for MAX-lab this was a decisive advantage that perhaps even its proponents deliberately made use of. It is a reasonable suggestion that the advocates of the MAX II project *did not* disclose all the—more or less certain—prospects of utilization of the envisioned facility, but instead counted on the possibility of having positive surprises of utility and scientific opportunity coming out of the lab in a few years. The "MAX-lab friends" in the council organization in the early 1990s may well have deliberately misled their superiors by not accounting for all the future expected costs. The council and the other actors in the science policy system may well have avoided full cost estimations and stuck with the distributed and incoherent funding model in order to conceal the full scope of the investment and postpone the bill.

These are obviously speculations, and even without them, the MAX-lab story contains important lessons about the built-in potential of synchrotron radiation facilities to come into being and grow strong despite seemingly unfavorable conditions. MAX-lab managed to evolve from a small-scale university project to a national resource and internationally competitive user facility in a step-by-step fashion, not only without comprehensive and coherent policymaking and funding schemes but without a system for policymaking and funding that could have made such decisions possible. While this makes MAX-lab exceptional in an international context, it is highly symptomatic of Sweden.

ACKNOWLEDGMENTS

I would like to thank Ralf Nyholm, coordinator of synchrotron radiation research at MAX-lab; Nils Mårtensson, director at MAX-lab; Mikael Eriksson, deputy director at MAX-lab; and Helena Ullman, administrative officer at MAX-lab, as well as all other noted interviewees, for their hospitality and generosity with access and information. I also thank the two anonymous reviewers for their helpful comments on earlier versions of this article.