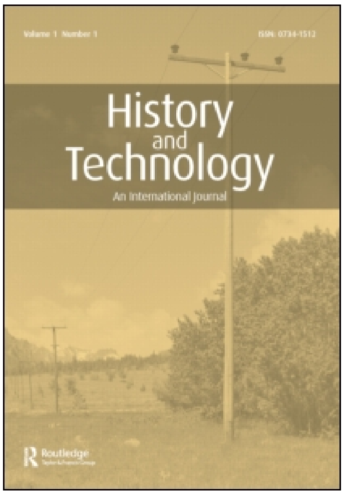

History and Technology

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713643058

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Online publication date: 23 June 2010

To cite this Article Nielsen, Henry and Knudsen, Henrik(2010) 'The troublesome life of peaceful atoms in Denmark', History and Technology, 26: 2, 91 — 118

To link to this Article: DOI: 10.1080/07341511003750022

URL: http://dx.doi.org/10.1080/07341511003750022

History and Technology
Vol. 26, No. 2, June 2010, 91–118

The troublesome life of peaceful atoms in Denmark

Henry Nielsen and Henrik Knudsen*

The Danish Atomic Energy Commission (AEK) was created in 1955 with the remit to promote 'the peaceful exploitation of atomic energy for the benefit of society.' Between 1956 and 1963 the AEK, which had been preceded by a number of early private nuclear initiatives, established an ambitious atomic energy research facility at Risø, some 40 kilometers west of Copenhagen. For most of this period the AEK was chaired by the celebrated physicist Niels Bohr. In spite of strong support from relevant actors in Danish society and Risø's management, Denmark never built commercial nuclear power stations. Today Risø has undergone a complete metamorphosis from atomic energy research facility to a national laboratory, doing research and development on a broad range of alternative energy sources. Using concepts and approaches like national innovation systems and technological nationalism, the present paper will explore why and how this remarkable development took place.

Keywords: nuclear energy; international cooperation; national innovation system; technological nationalism; basic and applied research; Cold War; Niels Bohr

Introduction

Many competent historians have researched and published a great number of scholarly articles and monumental monographs on the nuclear programmes – each of them unique – of the four great powers after the Second World War: the USA, Great Britain, France, and the USSR.[1] The situation is much more blurred, however, as far the small and medium-sized countries of the World are concerned. So far it has mainly been national historians who have charted the development of nuclear power in these countries and most of their results have been published in national language publications. This tends to make comparisons between different countries difficult. We believe, however, that proper comparative studies of a few neighboring countries could produce a more nuanced understanding of how combinations of common international and unique national factors have interacted to create the present ranking of countries with respect to nuclear generated electricity, and so be valuable to contemporary discussions.

The four Nordic countries, Denmark, Norway, Sweden, and Finland together offer an interesting case. Each of these countries is in the top 10 of the International Monetary Fund's October 2008 list of income per capita in different countries,[2] each of them is a modern welfare state with a high degree of economic and social homogeneity; for almost 200 years the countries have lived together in peace, and for almost as long they have developed close political, economic, and cultural contacts across the borders. In one respect they are light years apart: while neither Denmark nor Norway produce electricity by means of

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ISSN 0734-1512 print/ISSN 1477-2620 online

DOI: 10.1080/07341511003750022
http://www.informaworld.com

nuclear power, in 2007 nuclear power stations generated as much as 46% of Sweden's electricity production and close to 27% in Finland.[3]

How did it come to pass that these four countries with so much in common show such big differences in the field of nuclear energy?[4]

We shall not be able to provide a complete answer to this question in the present paper. However, we take a necessary step in that direction by analysing Denmark's unique nuclear energy path in terms of key concepts that may also be relevant to other countries and thus will facilitate international comparisons. The three key concepts are: National Innovation System, Technological Nationalism and the Extraordinary Human Factor.

(1) *National innovation system* (NIS). Although this concept has roots way back in history,[5] the modern version did not emerge until the 1980s. As a reaction against the inability of neoclassical economic models to explain recent trends in the world economy, the concept of national innovation system (NIS) was introduced as a heterodox framework for analysing innovation processes in various countries.[6] NIS emphasizes 'the influence of national education system, industrial relations, technical and scientific institutions, government policies, cultural traditions and other national institutions.'[7] In the present article, we follow Christopher Freeman in his definition of a system of innovation as '… the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.'[8] We do not intend to apply NIS as a formal theory for studying the various attempts to introduce nuclear power into Denmark, only as a pragmatic, heuristic framework. As such it points to and provides a useful overview of some salient structural traits in the national context that would not, perhaps, be apparent from a more traditional STS-approach like Actor Network Theory. Adopting the NIS framework allows us to make use of insights into the specific national context that have been provided by researchers from this and similar methodological perspectives.[9]

(2) *Technological nationalism.* Recently, historians have emphasized the importance of a transnational approach to the history of technology.[10] The development of nuclear energy since the mid 1950s is a history in which geopolitical concerns, transnational organizations, and corporations play a major role. Transnational organizations like IAEA and Euratom were instrumental mediators for cross-border flow, circulation, diffusion and distribution of knowledge, technologies, people, and artefacts thus promoting and shaping local technological developments. *Prima facie* such global frameworks seem to narrow down the space for national technological trajectories. At the same time nuclear energy constituted an ideal tool for war wrecked states to project a strong image of national identity, technological proficiency and modernity. In short, nuclear energy was also a field shaped by technological nationalism or techno-nationalism.[11] By techno-nationalism we denote the belief, held by prominent historical actors, that a given nation can only survive as a technologically advanced nation by developing and adopting certain types of technology. In this particular case it may even be appropriate to speak of nuclear nationalism.

(3) *The extraordinary human factor*. There is, however, a latent danger in only using the NIS concept, or any other systemic concept for that matter, as a basis for history writing and that is individuals tend to be treated as actors with roles more or less predetermined by the actor group to which they belong, such as politicians, industrialists, utility managers or reactor engineers. This may be a reasonable way to deal with a complex situation as long as the focus is the big picture, but in singular cases such procedures may result in a distorted picture of what actually happened. An example of such an instance is when an individual with a unique status in his/her homeland becomes heavily engaged in the case in question. In this situation the person's influence, under certain circumstances, may turn out to be so great, that he/she can decide the agenda more or less as he/she sees fit. We argue that the

Danish atomic physicist Niels Bohr exemplifies such a uniquely positioned individual, and therefore that 'the extraordinary human factor' may play a much larger role in the case describing Denmark's nuclear development during the first two decades after the Second World War than in the corresponding cases for Norway, Sweden, and Finland. This does not imply that we subscribe to hagiographic history writing. As will become clear in the next sections, Denmark's nuclear energy history is certainly not the story of a lonely hero who solves all problems and does all the right things.

Combining these three key concepts provides a flexible framework that allows for an account of history that highlights the interplay between the main actors and the structural and contextual features. We aim at a narrative that strikes a balance between the levels of actors and structures.

Getting started

When the Second World War drew to a close the USA was the only nation in possession of nuclear weapons, the terrible potential of which had been demonstrated to the world through the bombing of two Japanese cities, Hiroshima and Nagasaki, in August 1945. Although many attempts were made over the next few years to get all fissile material and nuclear technology under United Nations control, these attempts invariably failed for two decisive reasons. First, the USA wanted to keep the 'atomic secret' for as long as it possibly could, and second, neither the new major power, the USSR, nor the two older and now less important powers, the UK and France, would accept being relegated to second rank nations without possibilities to participate in the development of nuclear technology in general, and nuclear weapons in particular. Thus, immediately after the Second World War, the USSR and the UK (and France a little later) commenced crash programmes with the aim of producing nuclear bombs as quickly as possible. A few years later it became obvious that the attempts by the USA to keep its nuclear monopoly had failed. In fact, the USSR tested its first nuclear device in 1949, the UK in 1952, and from 1950 onwards both the USA and the USSR had programs to develop hydrogen bombs with explosive powers equivalent to more than a thousand Hiroshima bombs. In addition, small countries like Norway, Sweden, and the Netherlands had initiated nuclear projects that in a few years could very well result in a number of national nuclear reactors, perhaps even national nuclear bombs. It was like a chain reaction of events that in 1953 led to drastic changes in the US government's nuclear policy.

This new policy, called 'Atoms for Peace,' was introduced to the world on 8 December 1953, when president Dwight D. Eisenhower gave his now famous speech in front of the UN general assembly. At the core of 'Atoms for Peace' was the idea to create a new atomic energy agency (IAEA) under the auspices of the United Nations. The major powers were invited to donate a fraction of their stockpile of fissionable material to IAEA, which would have the authority to help non-nuclear states develop peaceful uses for atomic energy if and only if they were willing to let IAEA keep the necessary fissionable materials under control.[12] 'Atoms for Peace' became a great success, but the imagined central role of IAEA in Eisenhower's proposal eventually became substituted with bilateral agreements between one of the nuclear powers and its non-nuclear client states. This was also what happened in the case of Denmark.

In marked contrast to Norway and Sweden, Denmark did not embark upon any projects aimed at utilizing nuclear energy for civilian, or military purposes in the first decade after the Second World War. This may seem surprising given Denmark's almost total dependence on imported coal and oil to cover its energy needs. Although Denmark lacked uranium and heavy water, and this was clearly a serious drawback for the country's nuclear aspirations, it is perhaps even more important to consider AEK chairman Niels Bohr's position in Danish society when looking for explanations of Denmark's nuclear heritage. Bohr was considered in a class of his own; a national treasure. No responsible minister would ever think of taking any action concerning the topic of 'atoms' without consulting the nation's own legendary physicist, but this was precisely where Bohr's weak spot lay: in the exploitation of nuclear energy. As a member of the team of scientists largely responsible for developing the atom bomb in Los Alamos, Bohr had come under scrutiny from the US security authorities. Because of activities that included communicating with the Soviet nuclear physicist Peter Kapitza, Bohr was considered a security risk by Churchill and Roosevelt.[13] Consequently he was obliged to promise not to divulge any atomic secrets, much less take part in any work to help develop atomic energy.[14] After Gerard R. Pomerat of the Rockefeller Foundation had visited Bohr in June 1946 he made the following entry in his meticously kept diary: 'Spent afternoon with Professor Bohr who asked that major share of our conversation not be put down in writing. He is in a very difficult position due to his knowledge of the bomb and has decided to do no work which might be misinterpreted. … Says that Denmark is the only free country in Europe which hasn't set up an atomic energy commission … .'[15] Obviously, Bohr wished to pursue nuclear energy research more actively than he felt allowed.

The US policy on Bohr amounted to a kind of Berufsverbot putting severe constraints on his possibilities to continue and develop activities at his own institute even concerning projects without direct links to nuclear energy. One area of tension was radioisotopes, a field that constitutes an important part of the prehistory of the Danish nuclear energy program. Since 1935, the Rockefeller Foundation had supported a research project in 'biophysics' (i.e. biological and biomedical research using radioisotopes) at Bohr's institute in Copenhagen, run by a triumvirate consisting of Niels Bohr, the Danish zoophysiologist August Krogh, and the Hungarian chemist George de Hevesy. Under this project a cyclotron became operational shortly before the war, thus securing the researchers access to a handful of biologically relevant radioisotopes.[16] With Denmark occupied by the Germans, the Rockefeller Foundation withdrew its support in 1941, when the USA entered the war against the Axis powers.

Immediately after the war the above-mentioned trio resumed negotiations with the Rockefeller Foundation in the hope of gaining financial support for further research within this field, but US concerns over secrecy and security meant that the foundation hesitated and sidestepped the issue for nearly two years, and it was May 1947 before the Copenhagen group recieved the green light for their application.[17] Explaining the foundation's policy a few years later Pomerat plainly said, that 'in 1946 … the shadow of US dissaproval of B[ohr] made RF [Rockefeller Foundation] participation in isotope activity somewhat difficult.'[18] One of Bohr's key concessions during negatiations with the foundation was that work with radioisotopes would be relocated from his own laboratories and so it came that the Laboratory for Zoophysiology became the center for isotope research in Denmark in the early 1950s.

After the war an ample variety of cheap radioisotopes became available from the Manhattan Project's plutonium producing reactors. Pointing to security concerns export thereof were not allowed even to friendly nations in Western Europe. Bohr wanted US radioisotopes for Denmark. During the summer of 1947 he pushed the AEC hard, mobilizing sympathetic US scientists to his cause in order to soften the exaggerated security concerns of the AEC and Lewis Strauss.[19] Eventually Bohr succeded and the 'American' isotopes began arriving in Copenhagen at the start of 1948. Bohr considered radiobiology as an important preparation and training ground for nuclear science and technology in a small country without an atomic energy commission.[20] Nevertheless, Denmark was obliged to keep its ambitions concerning nuclear energy on hold until the US gave the go-ahead in 1953. As permanent secretary in the Ministry of Employment and Social Affairs, Hans Henrik Koch, a close associate and confidant of Niels Bohr and later an active member of the Danish Atomic Energy Commission, diplomatically put it: 'Indeed, it was not until others had taken up the idea that we [Denmark], too, ought to begin working with the practical, peaceful use of atomic energy, and particularly after Bohr had been brought to understand that leading circles in Britain and later the United States would look with sympathy and support upon such Danish efforts, that Bohr wholeheartedly espoused the idea of a Danish atomic energy programme.'[21]

A few months before the American president Eisenhower addressed the UN General Assembly and delivered his much acclaimed 'Atoms for Peace' speech on 8 December 1953, there were signs coming from Washington that hinted at an imminent relaxing of the rigid US nuclear policy.[22] These signals motivated the Danish Academy of Technical Sciences (Akademiet for de Tekniske Videnskaber, ATV), a private organization founded in 1937 with strong ties to the industrial sector, to propose in early November 1953 that Denmark appoint an atomic committee 'to follow the international work developing the industrial use of atomic energy and, based on this, to make such proposals as might be appropriate for a potential Danish working programme.'[23] The academy's council agreed to urge Niels Bohr and J.C. Jacobsen, both professors at the Institute for Theoretical Physics, and Torkild Bjerge, a professor at the Danish Technical College, to sit on the committee. All three accepted the challenge. The resulting body, called the Atomic Energy Committee, broadened its base when it invited civil engineer Haldor Topsøe on board. Topsøe, a young chemical engineer who ran his own consulting firm, was well acquainted with both Bohr and Bjerge, and it was this small group of people that did the preparatory work. Although the state soon entered as a major player in the atomic energy field, ATV continued to serve as a non-governmental promoter of industrial development based on nuclear technology, particularly in relation to reactor design and radioisotopes.

Denmark was clearly a late starter in the nuclear-energy race, but when the country finally started moving, it quickly got up to speed. The time had come to catch up with Norway and Sweden, which had a good head start. Denmark's new Atomic Energy Committee made use of Bohr's personal acquaintance with Lewis Strauss, the chairman of its US counterpart, and with leading figures in the British atomic energy establishment (John Cockcroft and Edwin Plowden) to achieve favorable arrangements for supplies of enriched uranium and heavy water in sufficient amounts to allow Denmark to begin buying and building its own experimental nuclear reactors. Right from the start the Danish committee attempted a two-sided, transnational nuclear strategy in order to keep all technological options open and avoid a situation of unilateral dependency.[24] Before long it turned out, however, that such arrangements were contingent upon the formation of an official Danish atomic energy organization mandated by the Danish government which could enter into binding contracts with the national atomic energy organizations in the USA and the UK. In a confidential conversation between Bohr and Strauss, the latter stated yet another precondition with a clear Cold War message, i.e. no communists were to be employed at the forthcoming Danish atomic energy research facility.[25] Thus, the USA was more than willing to help friends and allies to cross the threshold to the atomic age, but Strauss' remarks leave no doubt that the American 'Atoms for Peace' program should also be seen as a continuation of earlier US initiatives to 'win the hearts and minds' of scientists and engineers in Western Europe in order to create a transatlantic hegemony based on consensus instead of fear.[26]

Winning the hearts and minds of the general public was the obvious motive behind an expensive, but apparently very effective 'Atoms for Peace' campaign in Denmark in the Summer of 1955. The campaign was centered around an exhibition called Atomet i Hverdagen ('The Atom in Everyday Life') and an accompanying 32 page pamphlet. Developed by the US Information Service (USIS) with Danish nuclear scientists as consultants the exhibition was shown in Denmark's three largest cities, Copenhagen, Aarhus and Odense, in the Summer of 1955. Approximately 140,000 Danes attended the exhibition and with more than 190,000 pamphlets distributed, the campaign was deemed a great success by USIS representatives as well as high-ranking Danish officials. The mayor of Aarhus, Unmack Larsen, for example, in his opening speech said that whereas atomic power until recently had only given rise to fear, an air of optimism and hope was now replacing the fear as a consequence of Eisenhower's 'Atoms for Peace' initiative.[27] The American cultural attaché at the American embassy in Copenhagen commented: 'It [the exhibition] came here at a most opportune time, as we all know, Denmark just recently embarked upon a program of all-out support for developing the potentials of nuclear energy. To what extent President Eisenhower's Atoms for Peace proposal has something to do with these Danish developments I can, of course, not say. But I wouldn't be surprised if there were some loose, hard-to-define causal relation between the two – something in the nature of a mild chain-reaction … .'[28]

Danish opinion polls taken shortly after the campaign indicated 'an 84 percent affirmative reply to the Barometer question, "Have you heard or read of any peaceful, non-military uses of atomic energy?"' as well as a large majority thinking that 'atomic energy will prove more of a boon than a curse to mankind.'[29] With these figures as well as recent Danish initiatives in mind (see next section), it is no wonder that well-informed Americans thought Denmark would be among the first European countries to exploit nuclear power for electricity generation.[30]

Besides the general motives behind the 'Atoms for Peace' initiative, US policies towards Denmark appear to have been motivated by two national security issues. One was to reduce Danish reliance on coal imported from the eastern block (Poland in particular), which in the period between 1948 and 1951 amounted to 40–60% of Denmark's total coal supply. In specific situations Poland had actually succeeded in forcing Denmark to export strategically important industrial goods, such as spare parts for trucks. The other major motive being to reduce the strong and still vigorous commitment to 'neutralism' among many Danes, a commitment that the USA constantly felt as a threat to vital US and NATO strategic interests, such as the right to build and use military bases in Greenland.[31]

Involving the state

In early 1955, the Atomic Energy Committee approached the Danish government stating that it had now fulfilled its mission, and that further progress depended on the government's will to provide moral and financial support. The committee received a warm welcome from the Social-Democratic government, and the finance minister Viggo Kampmann, whose ministry would be responsible for atomic issues, was among the most enthusiastic. Kampmann was an ardent supporter of the cause, belonging as he did to the group of modern social-democratic economists who were convinced that the path to greater wealth and increased welfare for Danish society as a whole should follow a path of increased education and research, particularly in science and technology.[32] Kampmann readily promised that he would do what he could to obtain the necessary funding of about DKK 100 million – the

Atomic Energy Committee's estimated cost of building an atomic research facility that would bring Denmark neck-and-neck with the other Scandinavian countries.[33]

During the spring of 1955 the government appointed a Preparatory Atomic Energy Commission, chaired by Niels Bohr, that was empowered to contract with the USA and the UK for the delivery of two (soon to become three) nuclear research reactors for a Danish atomic research site. The contracts were signed and made public in the UK, the USA, and Denmark simultaneously on 10 June 1955, an event that was barely noted in the English and American press, but was treated as a sensation in Danish newspapers.[34] A few months later the commission decided that the new facility would be built on Risø, a peninsula in Roskilde Fjord 40 kilometres west of Copenhagen. Meanwhile, the political parties were involved in intense negotiations to settle on a more permanent solution; intense, though not overly problematic, as they took place in the atmosphere of global atomic optimism that followed in the wake of the Geneva Conference on the peaceful exploitation of atomic energy held in August 1955. On 21 December 1955, the Danish Parliament, Folketinget enacted legislation to establish Denmark's permanent Atomic Energy Commission, which had the remit to act 'for the promotion of the peaceful exploitation of atomic energy for the benefit of society.'[35]

The permanent Atomic Energy Commission (Atomenergikommissionen, AEK) consisted of 24 members selected to represent most of the established and organized stakeholders in Danish society, thus following the traditional pattern of corporativism in Denmark.[36] Initially the AEK consisted of 10 scientists from universities and colleges, seven industrialists, three representatives of the power industry (the Danish electricity plants), three union representatives and one civil servant (H.H. Koch from the Ministry of Employment and Social Affairs). Scientists held a dominant position in the AEK, reflecting the common view of nuclear energy as an inherently research driven technology and the conviction of Denmark's Social-Democratic government that science should play a decisive role in modernizing Danish society. Contrary to Kampmann's original idea, there were no politicians on the commission since Bohr had succeeded in convincing him that 'the atomic issue' was too important to let AEK become a battleground for politicians from different parties.[37]

AEK held a prominent, prestigious, and even semiautonomous position in the state administration. This privileged position, however, also isolated it from the main channels of industrial and trade policy as well as from the research organization bodies that emerged at about the same time. In some cases, as will become clear later on in this paper, Risø's privileged and lofty position was not always an ideal position from which to create strong and lasting partnerships with industrial companies and utilities.

AEK convened for the first time on 13 February 1956, choosing Bohr as its chairman and appointing an Executive Committee under the leadership of Koch to handle AEK's day-to-day administration. In his opening speech, finance minister Kampmann made it clear, that although Danish society had high hopes for AEK, he did not expect miracles over night. Nuclear power stations were still in their infancy, and AEK was not supposed to spend all its time and energy on developing nuclear reactors. In particular, he emphasized the importance of educating and training Danish nuclear technicians and qualifying Danish industry to be competitive in various niches of the expected gigantic global market for nuclear energy in the future. He also drew attention to the positive effects for society of the many radioactive isotopes that were soon to be produced in Risø's experimental reactors. In spite of Kampmann's considerable insight into many scientific and technical details, the organizational and strategic guidelines from the government for the new Danish research center remained unspecified. There was no grand political vision and no concrete scientific or technical milestones set from above.[38] The creation of AEK was not part of a comprehensive energy policy launched by the government; comprehensive energy and industrial policies would only see the light of day in Denmark in the last half of the 1970s.

Denmark's new Atomic Energy Commission had no problem staying busy, however, with an agenda that included: (1) hammering out the details of Denmark's cooperation agreements with the USA and the UK, (2) planning and supervising the construction of the extensive research complex on the Risø peninsula, (3) hiring hundreds of employees, and (4) last but not least, devising a strategy to ensure that the work carried out at Risø would, in fact, be 'for the benefit of society.' As for the first three items on the agenda, there can be no doubt that the AEK did a fine job. On 6 June 1958, roughly one and a half years after the establishment of the AEK, Risø was officially inaugurated. At the time, two of the site's experimental reactors (DR1 and DR2) had already been installed, to be followed by the third and largest reactor (DR3), which went critical on 16 January 1960. DR1 and DR2 were both of US origin, with capacities of 2 kW and 5 MW respectively, and their acquisition was partly subsidized by the US government through a reactor grant worth US$350.000.[39] DR3 was an English 10 MW high-flux materials test reactor of the DIDO type, similar to the reactors that had just been built at the Harwell and Dounreay atomic energy research facilities in the UK.[40] The completion in 1963 of the Risø hot-cell facility[41] was generally regarded as the final phase of construction, bringing the Danish research center up to the size planned by the AEK during the last half of the 1950s.

Total investments in the Risø facilities from 1956 to 1963 amounted to about DKK 150 million, and annual operating costs were roughly DKK 40 million in 1963 currency – making Risø a large and dominating cluster in Denmark's scientific and technological research landscape.[42] By 1963 the staff at Risø had swelled to about 750, a third or so of whom were scientists and engineers. Most of the people in this group were young and had graduated from the University of Copenhagen or the Danish Technical College only a few years earlier.[43]

Three things are worth noting. First, it has to be emphasized that Denmark's entrance into the atomic age was facilitated and achieved by international cooperation.[44] We have already seen how the 1955 'Atom in Everyday Life' exhibition and its associated pamphlet resulted from a collaboration between American and Danish authorities with a view to persuade the Danes to embrace the peaceful atom. Even more important, the people in charge of the Danish nuclear energy development, Niels Bohr in particular, had by mid 1955 succeeded in establishing strong connections to high ranking nuclear experts and politicians in the western camp, that from then onwards allowed a swift and in general also efficient transfer of state-of-the-art nuclear technology and know-how to Denmark. Although local Danish companies were engaged in the construction and mounting in all of the three reactors at Risø, the reactor designs, the 10 MeV electron linear accelerator installed in 1960, and the hot cell facility installed in 1963 were all imported from the USA or the UK.

Second, the three reactors at Risø were all research reactors, not power reactors. That means, they were primarily designed for the basic training of technicians in operating reactors, and for the production of many different radioisotopes to be used in scientific laboratories, agriculturel research fields, and medical treatment in hospitals. As we shall see, the founding fathers also imagined, that Risø's experimental reactors would be useful for irradiating and testing materials that were expected to be necessary for the development of future power reactors.

Third, the installation of the largest research reactor DR3 did not result from an unanimous decision by AEK, but only after protracted discussions in 1956–57 among key members of the commission. When the issue was on the agenda in August 1956, it turned out that the industrialist Haldor Topsøe and A.K. Bak, one of the electric utility representatives, preferred to buy a small power reactor instead of the materials test reactor advocated by Niels Bohr and the other scientists on the commission.[45] Topsøe and Bak argued that it would be much more fruitful for Denmark to get early experiences with a small scale power reactor than to add one more research reactor to the two already in the process of being installed at Risø. Niels Bohr and his followers disagreed. They argued that existing power reactors were far from optimal and that Denmark would risk being left behind with an obsolete power technology if AEK followed Topsøe and Bak's advice. More basic and applied research would be needed before a proper power reactor could be developed, and the English DIDO reactor was an optimal choice for basic nuclear energy research as well as for materials testing.[46] As usual, the majority of the AEK lined up behind Bohr. The majority included the two best known representatives from the utilities, Robert Henriksen and Jens Møller, which may seem surprising at first, but in fact reflected the utilities' basic understanding of Danish societal trends in the late 1950s. Why?

The fact is that the massive build up of state expertise at Risø had quickly created suspicion in prominent industrial and utility circles. Robert Henriksen was a very powerful man in such circles, and as such he was in a good position to represent the views of industry and the utilities. When in 1957 he reflected on the new Risø research institution, highlighting the potential dangers and shortcomings of the chosen organizational plans for the facility, not only was he a prominent member of AEK, and a former professor at the Danish Technical College, he was also chairman of ATV, director of the Danish Research Council for the Technical Sciences (Dansk Teknisk-Videnskabeligt Forskningsråd, DTVF), chief executive officer of NESA (a leading Danish utility company), and he held the chairmanship of the Association of Danish Electricity Producers (Danske Elværkers Forening, DEF). In his speech he noted that:

> A state financed technical and scientific research institute without close contacts with existing [Danish] industrial companies runs an immediate risk of becoming a self-inflated body that may only serve prestigious purposes, and if working well could even benefit foreign interests [i.e. government authorities and companies], and since it lacks a specific domestic purpose there is a danger that unnecessary interference in the agendas of the utilities and industrial companies could turn out to be a drawback instead of a real benefit for future development [in Denmark].[47]

This statement testifies to a certain tension between the scientific internationalism and thus transnational approach adopted by AEK and the straightforward industrial nationalism expounded by Henriksen. A year earlier, even before the facilities at Risø were up and running, Henriksen had indicated in public that the utilities would not rely solely on Risø, but would reserve their right to go ahead with their own plans.[48] Thus, in 1956, ATV took steps to create two independent private research organizations: (1) Danatom with the task of monitoring reactor developments around the world, and (2) Isotopcentralen, which would give advice to and provide services to Danish companies interested in using radioactive isotopes and tracer technology.[49] The rationale behind these two initiatives clearly reflects the industrial nationalism visible in Henriksen's speech.

In system of innovation terms, what we have seen so far is a large scale attempt by the Danish state, via generous financial support, to create a Danish nuclear system of innovation, with AEK and in particular the nuclear research facility at Risø as principal actors. In accord with the established innovation structures the state only supplied the opportunities but preferred to leave it to the the electric utilities, the interested industrial companies, and the relevant research institutions to make use of these opportunities. These structures had their roots in the unique Danish agricultural innovation system which had developed around the turn of the nineteenth century. This system was based upon collaboration between agricultural scientists at the the Royal Danish Agricultural College and various farmers' organizations, dairy cooperatives in particular, who together succeeded in creating a successful agroindustrial complex, which in the 1950s still dominated Danish exports.[50]

In comparison, the industrial and technical research was lagging behind, but grew rapidly after 1930. The Danish Technical College, the Danish Technological Institute, ATV, and a large number of industrial companies were instrumental in the formation of a number of loose networks and heterogenious technical and industrial innovation infrastructures.[51] Taking the agricultural system as a role model, they were not subject to state interference and user interests were directly incorporated into the systems.

The same tradition for non-interference by the state can be seen in the Danish electrification process. The state provided the necessary legislation, but no state capital was invested in the electricity sector. Almost all of the distribution companies – of which many were small – were consumer owned, and most of the large power stations were owned by distribution companies. Overseeing the electricity sector was the Association of Danish Electricity Producers (DEF), but its policy was determined by representatives from the boards of the larger power stations and distribution companies.[52]

Robert Henriksen, chairman of ATV and DEF, came from this background and the need to keep users in mind was taken up by the Atomic Energy Committee, which he played an active role in setting up in early 1954, but as his initiatives and speeches in 1956 and 1957 indicate, he had realized that the organizations he represented had lost control over what was happening in the atomic arena. The worldwide enthusiasm concerning peaceful atoms at the Geneva conference, the warm relations between influential atomic scientists and the Danish government, between Bohr and Kampmann in particular, and the unprecedented governmental financial support for nuclear research, worried Henriksen a lot. Foreseeing the state taking a more active role in the future development of the national electricity system than in the past, he reacted in 1956–57 against what he saw as attempts to create a Risø dominated nuclear system of innovation in Denmark. Already at this early stage he probably foresaw that such a system might eventually lead to public demands for nationalization of the electricity sector, a danger that would be enhanced if the third reactor at Risø was to be a power reactor. That Henriksen and Møller supported Bohr in favoring the DIDO type materials test reactor instead of a power test reactor was thus a natural consequence of Henriksen's analysis of recent trends in Danish society, a society which in his view was increasingly being dominated by Social Democratic ideas of welfare and state ownership.

Enthusiasm and trust

On 6 March 1956 the AEK appointed Torkild Bjerge as the technical-administrative director of the Risø Nuclear Research Center, and J.C. Jacobsen as the director of research. Working with the state's representative H.H. Koch, the two physicists began to interview and employ staff and to build up the scientific environments that would be endeavouring to fulfil Denmark's expectations.

Although it may seem peculiar, it is nevertheless a fact that Bohr, Bjerge, Jacobsen and Koch never prepared a detailed plan of how Risø was to be organized and which tasks the new institution was to embark upon.[53] Presumably the four key figures were in such agreement on the general outline and goals that they never felt the need to go into greater detail. Minutes of AEK meetings leave no doubt that especially Bohr and Koch were passionately opposed to any planning that might involve long-term constraints. As noted, Bohr, Bjerge, and Jacobsen were all physics professors at institutions of higher learning, and they therefore found it natural, perhaps so much so that it went without saying, that Risø would be organized in the same way as a large university faculty. The result was six departments, each led by a head with wide-ranging powers, who would answer to a joint governing body that mainly had a coordinating administrative function.[54] Once the governing body had decided on the future departments at Risø and appointed the six department heads, it largely left it up to each of them to put together their own department, which included making plans for research projects and employing the necessary scientists and technicians. There was a rule, however, that all expense-related decisions, whether they involved construction, experimental equipment, or employees, had to be presented to the governing body at one of the 'Friday Sessions' held weekly at Risø. Here Koch would meet with the two directors, Bjerge and Jacobsen, and all of the department heads. There are no minutes from these Friday sessions, but accounts from people working at Risø at the time all agree on one significant point: only very rarely were requests from the department heads refused. The usual procedure was that a list of all requests – sometimes diplomatically reworded following suggestions by Koch – was passed on for approval by the Executive Committee of the AEK, which normally convened in Copenhagen on the following Tuesday. By virtue of his inclusion in the 'Friday Session' and the 'Tuesday Session,' Koch played a crucial role in smoothly and painlessly resolving the multiplicity of problems that arose. The fact that no minutes were produced for the Friday sessions, the most important financial and strategic meetings between AEK and the management of Risø, gives an immediate impression of an organizational culture with abundant resources, limited financial control, and lack of real strategic coordination.[55]

Experimental work commenced in the years following 1956, as the departmental scaffold was gradually fleshed out with employees, and Denmark and the Danes had high expectations for the new nuclear research facility. From the instant the ceremonial shovel first pierced the topsoil in March 1956, the newspapers made sure that their readers were kept up to date on everything happening on the Risø peninsula. Topping-out ceremonies, appointments of directors and heads of department, reactors going critical, experiments that would excite the imagination – all links in a chain of events that was meant to quickly and safely guide Denmark into the atomic age.

Tentative efforts to submit critical reports or indicate potential dangers connected with the peaceful exploitation of nuclear energy were ruthlessly rebutted, either by the AEK or by Risø's directors, with all of the authority these two powerful authorities could muster.[56] This period was typified by positive attitudes toward science and technology, not least towards the peaceful utilization of nuclear energy, which was regarded as the only possible means to save industrialized civilization from an impending global energy crisis. The nuclear physicists and reactor engineers who were to realize this miracle were the new heroes of society. The enormous appropriations made to create and operate Risø – without any corresponding requirement in the form of clear-cut goals for the new institution – demonstrates the extent to which Danish society and government were willing to place their trust in Risø's scientific and technical elite.

The staff of the US embassy in Copenhagen, of course, monitored the nuclear developments in Denmark closely and reported back to the Secretary of State and/or AEC in Washington. Generally, the reports are very positive, but occasionally they contained a few sentences that indicate a slight uneasiness about the lack of clear goals and strong management within the Danish nuclear program. In late 1955, for example, secretary Ward P. Allen wrote to Gerard Smith at AEC:

> In Denmark, the personality and reputation of Niels Bohr, of course, dominates the picture and may perhaps lead to a feeling that 'we have got Bohr, that takes care of it.' Although of course a great scientist and a wonderful person, Bohr at 70 does not seem very interested in administrative or organizational matters, and with only a part-time [AEK] and an inadequate staff, there is no one else to take the lead.[57]

In short, Niels Bohr is an extraordinary human being, but because of his age and his scientific interests he may turn out to be a hindrance rather than a promoter of nuclear power in Denmark.

Exploring the technoscientific potential in experimental reactors

Surprisingly, perhaps, nuclear energy research in Denmark had a strong emphasis on basic, or 'pure' research from the very beginning. Basic research was mainly cultivated in Risø's departments of Physics and Chemistry. A review of the research projects in both departments around 1960 has shown that more than half of them can be categorized as basic science.[58] The predominance of university researchers in the AEK partly explains this. Another reason for the large share of basic science is that Risø was established at a time when basic research was ascribed great importance for technological development. Retrospectively termed 'the linear model of innovation,' this philosophy had been a cultural presumption among Danish scientists and scientifically trained engineers since the turn of the century,[59] but had gained new currency through the publication of the Vannavar Bush report in 1945.[60] This report was certainly known to most high ranking scientists within the budding Danish research organizations like AEK. With this in mind, it is not surprising that AEK's scientific elite in 1955–56 strongly favored the procurement of experimental reactors over test power reactors for its reseach facility, Risø. One should not forget, however, that these experimental reactors had a much broader technoscientific potential than only being advanced research tools in Risø's efforts to develop new variants of power reactors. The same three experimental reactors that were used by nuclear engineers for materials testing and as a training ground for the operation of power reactors, also functioned to spearhead facilities for basic physical and chemical research as well as for a broad range of technological research projects. In fact, all of Risø's departments used DR1, DR2 and/or DR3 as workhorses in many of their research projects.

Neutrons could be removed from the reactors in the form of intensive neutron rays which among other things were utilized to measure their lifetime, to examine their interaction with various atomic nuclei, to study physical and chemical transformations in irradiated materials, and to produce many different radioisotopes for specific purposes. Even though the basic research projects at Risø sometimes ran into problems, many of them were fairly successful.[61] This was mainly because the senior scientists had talent, experience and helpful contacts at scientific centers in Denmark and abroad, but it was also because Risø had high-quality laboratories and equipment, including its own powerful, state-of-the-art neutron ray facility.[62]

Risø set up a distribution program for radioisotopes and radioactive labeled compounds that was shaped by a more or less tacit understanding among Nordic countries reached through the so-called 'Kontaktorgan,' a vehicle for Nordic cooperation formed in 1957. Seeking to avoid competition with an existing Norwegian distribution program, Risø concentrated on short-lived radioisotopes. In-house at Risø, radioisotopes were chiefly used for basic research in nuclear physics and as radioactive tracers for the plant and animal experiments going on in the Agricultural Department at Risø. However the better part (in some years 60%) of the total output went to Danish hospitals where radioisotopes were used for clinical purposes and in medical research.[63]

We know today that the one-dimensional perception of the relationship between science and technology embodied in the linear model is greatly over-simplified. That is why, looking back, it is not surprising at all that most of the Risø departments found it difficult to present genuine successes when it came to applied science; 'successes' meaning examples of research done at Risø that led to saleable products manufactured by Danish companies. The Electronics Department at Risø is a good example. Led by the engineer G.K. Frölich-Hansen, this department's employees developed a series of instruments designed to measure different types of radiation. Frölich-Hansen himself saw this work as lending a helping hand to the Danish electronics industry, which he encouraged to further develop and market Risø's products. The only problem was that the companies were not interested. Not feeling that they had a problem, they saw Risø's concern as condescending, something they would much rather do without. The aggravation pervading the electronics industry is evidence in the entire sector's remarkable intransigence towards Risø in 1963, which was also the *annus horribilis* of another Risø department, as described later in this paper.[64]

Fortunately for Risø there were high points, too, many of which were accomplished by the Agricultural Department. Its research was supervised by the Royal Veterinary and Agricultural College, which had a long-standing tradition for doing applied research and closely collaborating with the agricultural sector's own organizations. Building on this tradition, it was natural for Danish agriculture to regard the Agricultural Department at Risø as part and parcel of the well established Danish agroindustrial innovation system, as yet another location – one that enjoyed the use of hitherto inaccessible technical facilities – that could do agronomic R&D work. A gamma radiation source was set up on one of the experimental fields at Risø in 1957, enabling the scientists to subject selected crops to controlled doses of radiation and thus investigate the potential of gamma radiation in selective plant breeding and disease control. In addition, Risø carried out a series of experiments using radioactive tracers to study biological processes in plants, animals, and the topsoil. These and numerous other experiments received good coverage in the press. It was easy to explain their purpose to the layperson, and because the Agricultural Department's down-to-earth experiments were closely linked to agricultural practices, it was often cited as an example the other departments at Risø would do well to follow.[65]

Reactor-engineering research and development

Already at the planning stage, Bohr, Koch, and Bjerge agreed that the new experimental complex had to keep up with nuclear-reactor developments. In the summer of 1957, a year before Risø's inauguration, the newly hired staff in the Reactor Department found themselves facing a critical choice: should they put all their efforts into developing an independent Danish reactor type? Should they try to join a large, foreign-dominated reactor development project? Or should they employ their limited resources to conduct a series of less ambitious research projects linked to existing reactor types?

The discussions took place against an international backdrop of optimism concerning the future of peaceful atomic energy. The atomic euphoria at the 1955 Geneva Conference on Peaceful Uses of Atomic Energy was still in the air – in October 1956 the UK had inaugurated Calder Hall, Britain's first dual purpose nuclear power plant[66] (60 MWe), based on gas-cooled, graphite-moderated magnox reactors consuming natural uranium; the USA was just about to connect its first civilian nuclear power station (60 MWe) to the grid, the steam for the turbines being generated by boiling water reactors (BWR) using light water for moderation as well as cooling, and slightly enriched uranium as fuel. In the UK, the USA, and elsewhere a number of other reactor types, known to insiders by acronyms like PWR, AGR, SGHWR, HTGR were actively being explored.[67] Finally, in May 1957 the 'Three Wise Men,' a committee put together by the foreign ministers of the Six (France, Germany, Italy, The Netherlands, Belgium, and Luxembourg), published 'A Target for Euratom,' a report that recommended high growth in nuclear produced electricity over the next decade, aiming at 15 GWe by 1967.[68] In short, there was a widespread feeling among reactor engineers that everything was possible, and that nobody knew which type of reactor would eventually turn out to be the winner in the race for 'the best power reactor.'[69]

Based on their deliberations, the young reactor engineers at Risø chose to initiate an investigative project to study which materials could be used for building a Deuterium-moderated Organically-cooled Reactor, and they named their project DOR. They would also study other factors, such as the reactions of fuel rods, moderators and coolants subjected to conditions of intense radiation. Moreover – and perhaps most importantly – the DOR project was intended to give Risø's untested reactor engineers the practical experience they would need if they were to attempt to create any sort of serious cooperation with the Danish electricity plants and the industrial sector to design and build a nuclear-powered reactor.

There were three reasons for choosing to go with the DOR, rather than any other reactor type. First, given the choice, the enthusiastic reactor engineers at Risø preferred to work with a type of reactor that had not yet been studied elsewhere, at least not in any great depth.[70] Second, they deemed that this type of reactor would not present any great constructional problems, which ought to give Danish industry a fairly good chance to participate in developing the potential DOR power plants of the future. Third, the DOR was capable of running on natural uranium. As uranium deposits had been found on Greenland, this meant that Denmark's might have the potential to become self-sufficient in energy production.[71] If succesful the DOR project would carve out a specific and relatively independent technological pathway towards a nuclear powered future. The ambitious DOR project constituted the spearhead in Risø's and AEK's policy of techno-nationalism.

The directors of Risø found these arguments so compelling that the investigative project was allowed to progress smoothly for the first three to four years. Staff working on the DOR project carried out a series of detailed technical studies and model-based calculations aimed at solving the problems that would inevitably crop up in this type of reactor. Nothing about the project was very dramatic – but then again, none of its findings were ever close to becoming immediately useful either. Contributing to the relaxed atmosphere and slow progress in Risø's Reactor Department in the period 1957–1960 was the rapid disappearance after 1957 of the early widespread international optimism concerning the prospects for nuclear power. Already at the Second UN Conference on Peaceful Uses of Atomic Energy, that took place in Geneva in September 1958, the previous lofty optimism had been transformed into a more realistic appreciation of the formidable technical and economic problems associated with the complex nuclear fuel cycle which had to be solved before uranium could become a true competitor to fossil fuel in the power business. Indicative of the changing mood was Euratom's failure to realize the 1957 predictions in 'A Target for Euratom' to have 3000 MWe installed nuclear capacity in its membership countries by early 1963, and a further 3000 MWe each year thereafter to reach 15,000 MWe in 1967.[72] With abundant fossil fuels on the market and electricity demand leveling off shortly after the Suez Crisis in 1956, an invitation by the USA and Euratom to European utilities to submit proposals for six to eight reactor plants by 1 September 1959, apparently only resulted in one proposal.[73]

Then, in 1960, something happened that would decisively alter the course the Reactor Department had followed so far. The head of the Physics Department, Otto Kofoed-Hansen, had spent several months in the autumn of 1959 travelling around and studying various atomic facilities, most notably the private nuclear physics and defence contractor General Atomics in San Diego, California, where he had had the opportunity to compare the development of reactors in the USA with the R&D efforts going on at Risø. In the late 1950s General Atomics developed the landmark TRIGA reactors which became the world's most widely used nuclear research reactors, and so the comparison did not reflect favorably on Risø.[74] Upon his return to Denmark, Kofoed-Hansen penned a confidential memo to the directors of Risø, harshly criticizing the facility's DOR project, or at least the way in which the project was being managed. According to the memo, the Reactor Department at Risø lacked all of the things that General Atomics had, namely: (1) an experienced staff, (2) good contacts in the industry, and (3) a well-defined project. Kofoed-Hansen rounded off his memo by imploring 'our topmost administration' to help chart the way back onto to the right course, since, as he put it, 'researching out into the blue is a game of chance, where we, with our small potential, have a first-class opportunity to draw a big blank.'[75]

Although there is no trace of the memo in the minutes from meetings of the board of directors of Risø or the AEK, there are clear indications that it made an impression. At any rate, in August 1961 the AEK wrote an official letter to Danatom, which had been formed by the electricity plants and a number of industrial enterprises back in 1956 with the remit of keeping abreast of reactor developments around the world.

Right from the start Risø had been annoyed with Danatom, never really coming to terms with the fact that the electric utilities and the industry were not content with getting their advice and information from Risø alone. Now here was Risø, swallowing its pride and asking Danatom, the country's small, well-connected organization, if they might like to participate in developing an actual experimental DOR.

After mulling over the offer for several months, Danatom gave its reply. It was a resounding 'no.' Danatom had no confidence in the DOR concept, but if Risø insisted on pursuing the work with a DOR-type installation, Danatom recommended that Risø seek out foreign expertise in the area, as 'the possibility that we, here in Denmark, can independently lead the development of the DOR-type reactor to a level ahead of, or even equal to, what is happening in Euratom and Canada, seems slight, even if we were to direct all efforts into DOR.'[76] In short, Danatom believed the development of a DOR-type reactor could only succeed if Denmark's researchers and engineers became part of an international collaborative project. The creation of a small-scale national nuclear innovation system, as envisaged by Risø's Reactor Department, was deemed hopeless by Danatom.

The response infuriated the Risø reactor physicists and engineers, who repudiated all of Danatom's arguments, and Risø's next move was to try to go it alone, without involving Danatom at all.[77] In the autumn of 1962 – about a week before the death of Niels Bohr, still sitting as chairman of the AEK – Risø attempted, through the AEK, to establish a binding cooperation between Risø, a few selected Danish industrial companies, and the electric utilities to build an experimental DOR plant that the electricity plants were supposed to order. In other words: AEK/Risø at this particular moment made a serious attempt to establish a Danish nuclear system of innovation with the Risø's Reactor Department as leading actor. Sufficient progress was made for the AEK to form a committee, the Atomic Power Committee, consisting of representatives of the three involved parties, who were to investigate the matter further. In February 1963, even before the committee had begun its work, a frustrating and protracted conflict broke out between Risø and the Association of Danish Electric Utilities.

Afraid of losing their freedom to make decisions on purely economic and technical premises, the utilities made a public announcement on 22 February, stating that the time for introducing nuclear power into Denmark's electricity supply had not yet arrived. Eventually it would arrive, but when time was ripe, the Danish power companies would go for full sized, turn-key nuclear electricity plants. Only industrial corporations with a long record of reliability would be invited to make bids for the enterprise. In fact, the only place where the utilities could imagine Risø playing a constructive role was in what was somewhat condescendingly phrased as 'giving advice on a few technical questions concerning reactor materials.'[78]

With the utilities withdrawing their support, Risø was left in an almost impossible situation. All of a sudden a large part of the reactor oriented work at Risø appeared rather meaningless, a fact that was also obvious to the Danish Research Council for the Technical Sciences (DTVF), which had to live on a budget that was only a few percent of AEK's yearly budget. Consequently, DTVF demanded all reactor technological research at Risø be closed down and pleaded for a more equal distribution of government funds for research and development. The Government did not follow the advice of DTVF, but the staff members in Risø's Reactor Department were nevertheless frustrated by the situation. The enthusism had gone, and the DOR project soon fell apart. Strong centrifugal forces within the department contributed to the rapid decay. Indeed, in the course of two years the Reactor Department fissioned into no less than four separate units, each with its own plans for how best to survive the attacks that had hit Risø so suddenly and so destructively. One of these units was the department's metallurgy section, headed by Niels Hansen, whose motives and subsequent initiatives will be described in the next section.

Lasting four years, the conflict between Risø, the utilities, and the DTVF ultimately put an end to Risø's dreams of playing a leading role in developing a unique Danish reactor. Speaking in the language of Actor Network Theory, scientists and engineers from the Reactor Department, together with the managers of Risø and AEK, failed in their attempts to enrol allies and mobilize them in either the DOR project or subsequent projects. Risø did not succesfully manage to place the prestigious DOR project as an 'obligatory passage point' on the road to nuclear power in the Danish energy system.

One subsequent project was initiated in 1964. After the DOR project had been abandoned, it occurred to H.H. Koch, chairman of AEK's executive committee and F. Juul, head of what was left of Risø's Reactor Department, that the recent nuclear development in Sweden offered new and interesting possibilities. The partly state-owned Swedish company, AB Atomenergi, had finally completed a much delayed heavy water, heat producing reactor at Ågesta, and had contracted with ASEA and other Swedish companies to build a 200 MWe heavy water, power producing reactor at Marviken. From Risø's perspective the Swedish development looked inviting. Following high level negotiations between Koch, chairman of AEK's executive committee and Harry Brynielsson, director of AB Atomenergi, an agreement to facilitate cooperation on developing heavy water reactors was signed in Copenhagen on 7 January 1965.[79] The agreement gave Risø access to much of Sweden's extensive reactor know-how, thus allowing the Danish nuclear energy research facility to start a heavy water reactor project that looked much more realistic than DOR.

Before the agreement had been formally approved, Risø sought to establish a strategic alliance with the actors to which Risø had developed rather estranged relations over the past few years: the utilities, Danatom, and (parts of) Danish industry. In an attempt to obtain their support and collaboration, Risø proposed to set up a small committee, the Project

Committee, which included two members from Risø's Reactor Department, two from the utilities, two from interested industrial companies, and one from Danatom. The development project which Risø had in mind and which was dubbed DK-400, had as its goal a 400 MWe scaled up version of the Marviken reactor.[80] No simple undertaking, but to Risø's surprise the proposal was accepted by the other three parties, even the idea to let the engineer Søren Mehlsen from Risø's Reactor Department be in charge of the project.

Officially, the DK-400 project ran from 1965 to 1968, but it never became efficient, and it was never carried through to its end. The reasons for the failure are manifold but the most important ones seem to be:

(1) The project management favored the development of a heavy water reactor, whereas the non-Risø members of the Project Committee recommended a change to light water technology, whether Boiling Water Reactors (BWR's) or Pressurized Water Reactors (PWR's), which were gaining favor in the rest of the nuclear power community at that time. The slight bent from the early 1960s within the group of Danish utility managers to prefer light water reactors became a firm conviction after reliable information on General Electric's succesful bid in late 1963 for a 620 MWe power station at Oyster Creek – a New Jersey district close to rich coal fields – reached Western Europe in early 1964.[81]

(2) The project management was not endowed with sufficient authority to create a strong, interdepartmental project group at Risø. In fact DK-400 was obstructed by some of the department heads of Risø, because they never believed in the project, and had their own agendas.

(3) The DK-400 project was not a real transnational project. For this to be the case, not only papers and drawings but also experts of many different kinds would have been constantly moving between Sweden and Denmark – this never happened. Significant collaborations between Swedish and Danish industrial companies did not take place either.

All available evidence suggests that the non-Risø parties in the project never wanted DK-400 to be a success.[82] Probably they had only agreed to participate because the government would like to see them cooperate with Risø, and because they hoped that Risø – at least Risø's Reactor Department – would bleed to death in the process. This almost happened, but in 1967, when it was clear to everybody that Sweden was close to giving up further development of heavy water reactors, a lasting peace was finally negotiated between Risø and the electric utilities. As a result, the distribution of the two institutions' responsibilities changed completely. Up to this point, Risø had sought to play a leading role in the prospective introduction of nuclear energy into Denmark, though it had nothing to show for its attempts except an ongoing conflict with the utilities. Having learned from the experiences in other countries that had already built nuclear power plants, the utilities now accepted that Risø should handle the approving and supervisory function for any nuclear power plants built on Danish soil. In return, the utilities were entrusted with the supreme right to decide when Denmark was going to introduce nuclear power, and which type of commercial reactor the country would opt for.[83]

From this point on, Risø's reactor people could only sit back and wait for the day to come when the electrical-utility people decided that the time was ripe. When that day eventually came, in August 1972, the time was in fact over-ripe. Around the time the utilities and Risø were ready to present a joint proposal for the introduction of nuclear power in Denmark, the global community was beginning to question the blessings of nuclear power.

Even in late 1973, before the Danish legislation for licensing nuclear power plants was put in place, popular opposition to nuclear power had begun. By early 1974, The Organization for Disseminating Information on Nuclear Power (Organisationen til Oplysning om Atomkraft, OOA), a new and efficient grass-root organization, had been formed and was managing to capture the mood of uncertainty over nuclear issues and play on the lack of confidence in nuclear authorities. Over the following couple of years a heated and protracted debate for and against nuclear power engaged Danish society.[84]

Led by Risø's new director, the physicist Allan R. Mackintosh, the staff of the former Reactor Department became heavily involved in this debate by publishing newspaper articles and letters to editors, consistently maintaining that nuclear energy was the best solution for the vulnerable Danish energy supply system. Repeatedly, Risø employees argued against the fear and uncertainty expressed by OOA and other lay people. In retrospect, it appears that the institution was moving down an ever narrowing path, squeezed between its obligation to be an impartial adviser on nuclear issues and its traditional role as proponent of nuclear power.

In August 1976, when the nuclear issue was made the subject of a debate in the Danish parliament, opinion polls showed a substantial majority of the population to be against the introduction of nuclear reactors into the Danish electric power system, the main reason being concerns about safety and the nuclear waste problem. Facing the risk of splitting the party in two over the nuclear issue, the leaders of the ruling Social Democratic Party came up with a salomonic proposal in order to avoid a vote for or against nuclear power. They proposed – and the proposal was supported by a majority of parliament members – that a decision concerning the introduction of nuclear power in Denmark was to be deferred 'until an acceptable solution to the nuclear waste problem has been found.'[85] Despite expensive attempts over the following 8–10 years by Risø and the electric utilities to solve the nuclear waste problem, mainly by exploring the possibility for storing nuclear waste in deep underground Danish salt deposits, no fail-safe solution was found.[86] Consequently, in 1985 the parliament passed an act which excluded nuclear power from Danish energy planning, and thus brought an end to all attempts to introduce nuclear power into the Danish energy system.[87] Instead, the decisions of 1976 and 1985 became important milestones in the development of a new Danish energy strategy, relying on substantial energy savings, the utilization of a broad mix of fossil fuels from newly discovered oil and gas fields in the Danish section of the North Sea, and rapidly growing contributions to the country's reduced energy demand from renewable energy sources, wind energy in particular. This strategy has made Denmark self-sufficient in energy since the early 1990s.

Winds of change

The history of Risø, the national laboratory complex constructed in the 1950s with the clear objective of guiding Denmark into the atomic age, illustrates how difficult it can be for a new research institution to work out a strategy that delivers convincing results 'for the benefit of society.'[88] From the outset, Risø was dominated by people with a scientific university background, but without any overall plan for the institution. Instead, the various heads were allowed to set up their individual departments more or less as they saw fit. That is why the history of the research that took place at Risø during the first 20 years of its existence is not so much one history, but rather a series of diverging histories that, taken together, can provide insights into the interplay – or lack of interplay – between basic and applied science.[89]

Of all Risø's departments, the Reactor Department suffered the hardest defeats. Basing its decisions on the Bush report's presumption that science plays a pivotal role in developing new technology, but without any significant prior experience in reactor technology, the department optimistically pushed ahead in its efforts to develop a new type of reactor, placing its faith in the support it believed would come from the Danish electric utilities and the industrial sector. This support was not forthcoming. As early as 1963, the Reactor Department was forced into a defensive position, and consequently the heads of the department were gradually obliged to acknowledge that in their case, the Bush philosophy had led no where.

The head of the Reactor Department's metallurgy section, civil engineer Niels Hansen, had already come to this conclusion in the early 1960s. For several years he and his staff had been working with casing materials for the fuel rods intended for use in DOR. When the DOR-project was terminated in 1964, Hansen succeeded in spinning off his group from the Reactor Department and having it recognized as an independent entity: the Metallurgy Department. Hansen used the department's new-found independence to break with the reactor line known as DK-400, which the Risø directors strongly supported. Hansen believed that for far too long Risø had been doing 'applied research with no applications,'[90] and that the DK-400 project was in imminent danger of repeating the DOR scenario, the DK-400 being a heavy water reactor, whereas the electric utilities and Danish industry were more interested in light-water reactors.[91]

Hansen's view was backed by Helsingør Skibsværft og Maskinbyggeri (HSM), a Danish shipyard and machine company that wanted to enter the growing market for reactor equipment. In 1963, this led to the establishment of a long-standing cooperation between HSM and the unit that one year later would become the Metallurgy Department at Risø. Their goal was to develop fuel rods that could be used in Risø's own experimental reactors and in commercial light-water reactors. In technical terms the project was a success, as the partners were able to develop fuel rods that did well when tested in various foreign reactors during the 1970s. In commercial terms, however, the project barely got off the ground. One significant reason is that because Denmark itself never introduced nuclear power, there was never an actual domestic market for the product, and without a domestic market, the likelihood of doing well on the international market was virtually nonexistent. No one could have predicted this in 1963, however, and whether one chooses to call the development of fuel rods a success or a failure, the story serves to demonstrate that opinions diverged at Risø when it came to defining the meaning of research 'for the benefit of society.' It also demonstrates that a strong department head could sometimes set his own agenda, even at odds with the directors.

The other departments at Risø also had to adapt. Those least affected were probably the Physics Department and the Chemistry Department, both of which had aimed from the outset to become university-type departments that mainly concentrated on pure science. Their development over Risø's first decade confirmed that this had been a wise course to follow. During the harsh confrontations between Risø and its opponents following the facility's break with the electricity plants in 1963, the critics of the experimental facility would unfailingly emphasize that the reactor research and (portions of) the applied research at Risø were irrelevant to Danish society. On such occasions, conversely, the basic research done at Risø usually received acknowledgement. By being positive towards significant parts of the work going on at Risø, the critics were more at liberty to strike all the harder at those portions of the facility's program that they particularly wished to do away with. At no time during the first 10–15 years of Risø's history was there any question of cutting the grants given to basic research projects. This gave both the department heads and the large staff in the physics and chemistry departments an ever-stronger incentive to cultivate pure research.

The Agricultural Department, having close links to the Agricultural College with its century long recognized record for doing research 'for the benefit of society,' had no reason to make any radical modifications or innovations either. But two other departments, the Electronics Department and the Accelerator Department, followed in the footsteps of Niels Hansen's Metallurgy Department and thus helped pave the way for the dramatic changes that struck Risø after 1976 – the year the Danish government dismantled the AEK and indefinitely postponed the decision to introduce nuclear power into Denmark. Recognizing that applied research was important to Risø's survival, they also came to the conclusion that the prospect of failure is painfully real if such research does not take place in cooperation with users who are known in advance to be interested in the product. Adhering to Niels Hansen's motto 'No applied research without applications,' the Electronics Department, headed by Jens Rasmussen, took the initiative to cooperate with the electricity plants in a new area called 'control-room research.'[92] Likewise, Ari Brynjolfsson and Niels Holm from the Accelerator Department intensified their cooperation with the Danish pharmaceutical industry and the hospital sector to research and optimize irradiation techniques for sterilizing hospital equipment.[93]

The greater priority given to fundamental utility-oriented research in the Metallurgy, Electronics, and Accelerator Departments, combined with the sustained focus on pure research in the traditionally research-intensive departments of chemistry and physics, probably did influence the tendency of Risø's critics to regard the facility's basic research in a positive light. However, this tendency was also a result of the conviction held by the heads of these departments that whereas basic research will always make you smarter, applied research done with no specific application in mind often turns out to be a waste of time and energy. Few would dispute the claim that accepting this insight – a process that took a long time to permeate the entire organization – was a crucial precondition for the survival of the complex known today as the Risø National Laboratory, enabling it to weather the shifting economic, political and scientific climates it has seen during its 50 years in existence.

The period between 1976 and 1985 was a difficult time for Risø. With economic cutbacks, a pro-nuclear image at odds with much of the public, and a government unable to provide a clear direction as to what type of research to emphasize, Risø had to live with the constant risk of being shut down. In this uncertain situation various groups at Risø initiated projects that broadened the institution's areas of research and were to become of great importance for its survival. One particularly well known example is Risø's now famous Wind Energy Division, which has it origins back in 1975. At this critical moment for the Reactor Department, a few of its researchers became convinced that it would be possible to create a viable Danish wind turbine industry, and consequently they started working towards establishing a national test station for windmills at Risø. The official recognition of the test station in 1978[94] was a small but important step in the transition of Risø from the old nuclear research institution, financed almost entirely by 'free' state money, to the national laboratory of today doing research across a broad spectrum of energy and environment related projects (except nuclear!) and mainly financed through its ability to be competitive in the hunt for lucrative contracts from the burgeoning number of national and international strategic programs in this field.

Denmark never got nuclear power. In tune with the parliamentary decision in 1985 to exclude nuclear power from Danish energy planning, nuclear energy research was taken out of Risø's official mission statement the following year (only one month after the devastating accident in Chernobyl). The two remaining research reactors, and DR3 in particular, continued to serve as research instruments and as production facilities for radioisotopes until 2000 when the government finally decided to close the reactors and put them in line for decommissioning. Risø is now a national laboratory focused on alternative and sustainable energy systems. What ended with the spectacular parliamentary decision in 1985 was many years of vigorous work to introduce nuclear energy into the Danish society. The research institution Risø survived, however, but in a new form that proved more viable and robust than the original. Risø's leaders and most of its researchers adapted to and were to a large extent even able to anticipate the new societal agenda and shifting policy regimes.[95]

Conclusions

Viewing Risø's nuclear energy research activities during the 1950s and 1960s from a national innovation system perspective, it becomes obvious that because a strong Danish nuclear innovation system did not exist and never materialized, many of these activities took place in a kind of vacuum. From its very beginning the nuclear innovation system was only loosely integrated into the existing innovation infrastructures in the Danish society. Spurred by the founding fathers, Niels Bohr in particular, Risø's six original departments, and even subgroups within the departments, set up their own agendas and lived their own lives as they saw fit. True, important actors like the electric utilities and (big) industrial companies were represented in AEK, but being only minority factions their influence was almost always overshadowed by yet another actor, an actor befriended with Risø, namely the universities and other academic institutions that had the greatest number of seats in AEK.

Fearing nationalization via the backdoor, a united Danish electricity sector turned against the state financed research institution, Risø, as soon as the management of the Association of Danish Utilities (DEF) realized how much money and prestige the state was throwing at the research establishment. The dominant part of Danish industry, characterized by many small scale companies with low research activity, did not offer attractive development partners for Risø, like ASEA and Vattenfall did to AB Atomenergi in neighbouring Sweden. By far the most important development block in Danish business was the highly developed and highly specialized agricultural and bioindustriel complex, which over many decades had formed its own innovation system. This, in fact, included the Agricultural Department at Risø, but none of Risø's other departments were attracted to that complex until after 1985. Finally, Risø might have attempted to develop stronger collaborative links to the third innovation system centered around the Danish Technical College, Danish Technological Institute, and the large number of applied research institutions in this cluster. This, in fact, was proposed by several industrialists in 1963, when the fight between Risø and the electric utilities was at its peak, but Risø refused.

Nuclear energy research in Denmark started out being more or less organized as natural science research instead of technology development with the aim of creating a nuclear technological system that could stimulate industrial development in Denmark, and this remained the case until 1976. The chosen organizational structure was, as we have shown, far from optimal for supporting technological development and innovation, and the difficulties were aggravated by the management's lack of interest in large scale international collaborations that would have meant Risø making a committment. Risø's reactors and a good deal of the other main experimental facilities at Risø were imported from the USA and the UK. Plans and paperwork flew easily across borders between Denmark and neighbouring countries; but technological collaborations involving massive interchanges of money, machines, and manpower – which may have had a beneficial influence on Risø's failed reactor projects, DOR and DK-400 – were never seriously discussed.

The Danish government and the great majority of Folketinget gave high priority to nuclear energy research, but did not set any clear technological goals, nor milestones. Nuclear research was not seen in relation to a comprehensive energy policy, which only emerged after the oil crisis and the fierce energy debate between 1973 and 1976. Instead, the big spending on nuclear research was made possible by the strong, but diffuse fascination of the peaceful atom that was felt worldwide in the wake of the atomic energy conference in Geneva 1955, and by the international prestige that would accompany a Danish nuclear energy program. Nuclear scientists and scientifically trained engineers became Denmark's new heroes, and those who were in charge in the 1950s and 1960s wanted to create a unique Danish nuclear future by aiming at solutions that were clear manifestations of technological nationalism. Thus, Denmark obtained a scientist dominated nuclear innovation system, which was structured in a way fundamentally different from other Danish innovation systems, where user interests would normally be integrated much more directly. Thus it is no coincidence that most nuclear research at Risø became dominated by basic science projects, and that the researchers trying to do applied research would often find themselves doing 'applied research with no applications.'

In 1976, when the Danish government decided to postpone all decisions on nuclear power in Denmark, Risø came under heavy political and economic pressure, a pressure which supported the tranformation process that had been underway in certain departments since 1963. In the long run, Risø as a whole was opened to external influences that spurred the institution to seek new partnerships with existing high-tech companies and to engage in the development of new technologies, like advanced wind turbines. Thus, over the last 30 years Risø has gradually undergone a complete metamorphosis from the original state-owned nuclear energy research station to a modern national laboratory doing alternative energy and environmental R&D, and in the process, we argue, it has gradually become assimilated into the normal Danish innovation systems, which in turn have become more and more integrated into huge, multinational or transnational innovation systems.

Acknowledgements

A preliminary version of this paper was presented at the workshop: 'A Comparative Study of European Nuclear Energy Programmes,' Universitat Pompeu Fabra, Barcelona, 5–6 December 2008. Some of the themes treated in the present paper have previously been touched upon in Nielsen et al., *Til samfundets tarv* and in Nielsen et al., *Risø and the Attempts*. We want to thank Thomas Jonter and Karl-Erik Michelsen for stimulating discussions on the history of nuclear power in the Nordic countries. We also want to thank an anonymous reviewer for constructive criticism and helpful suggestions.

Notes

1. A few of the major works are: USA (Hewlett and Anderson, *The New World*; Hewlett and Duncan, *Atomic Shield*; Hewlett and Holl, *Atoms for Peace and War*; Mazuzan and Walker, *Controlling the Atom*); UK (Gowing, *Britain and Atomic Energy*; Gowing, *Policy Execution*; Gowing, *Policy Making*); USSR (Holloway, *Stalin and the Bomb*; Josephson, *Red Atom*); France (Hecht, *The Radiance of France*).
2. International Monetary Fund report: http://www.imf.org/external/pubs/ft/weo/2008/02/weodata/index.aspx (last accessed 30 June 2009).
3. Nuclear Energy Agency report: http://www.nea.fr/html/general/profiles (last accessed 30 June 2009).
4. The history of the nuclear program in Sweden is treated in Larsson, 'Kärnkraftens historia i Sverige'; Lindström, *Hela nationens tacksamhet*; Kaijser, 'Redirecting Power'; Glete, *ASEA under hundra år 1883–1983*; Leijonhufvud, *Parentes*; Fjæstad, 'Sveriges första kärnreaktorer'; Jonter, 'Sweden and the Bomb'; and Agrell, *Svenska förintelsesvapen*. Norway's nuclear history is described in Forland, *På leiting efter uran*; Forland, *Atomer for krig eller fred*; and Njølstad, *Fra atomskip til oljeboringsplattformer*.
5. List, *Das nationale System*.
6. See for example Freeman, *Technology Policy and Economic Performance*; Dosi et al., *Technical Change and Economic Theory*; Lundwall, *National Systems of Innovation*.

7. Freeman, ‘The National System of Innovation,’ 5.
8. Freeman, *Technological Policy and Economic Performance*, 1.
9. In particular Edquist and Lundvall, ‘Comparing the Danish and Swedish Systems,’ 265–98. See also Knudsen, ‘Konsensus og konflikt.’
10. See e.g. Van der Vleuten, ‘Toward a Transnational History,’ 974–94.
11. Hecht, *The Radiance of France*; Low, ‘Displaying the Future.’
12. According to John Krige ‘Atoms for Peace’ was a ‘polyvalent policy initiative,’ focusing on four dimensions: (1) the intention to divert attention from America’s ongoing Atoms for War efforts; (2) to divert skills and resources from the USSR’s military program; (3) to help American private industry to conquer the lion’s share of the expected huge market for commercial nuclear power; and (4) to score a propaganda victory by proposing a follow-up international scientific conference on the ‘benign and peaceful uses of atomic energy.’ See Krige, ‘Atoms for Peace,’ 161–4.
13. Aaserud, ‘The Scientist and the Statesmen,’ 32–3.
14. Physicist Torsten Gustafson to Prime Minister Tage Erlander, 10 June 1947, F111, 1. Tage Erlander Archive, Stockholm.
15. Gerald R. Pomerat diaries, entry 1 June 1946, RF, 12.2, Box 36, Rockefeller Archive Center, New York.
16. Aaserud, *Redirecting Science*, 165–212.
17. Gerard R. Pomerat diaries, entry 8 May 1947, RF, 12.2, Box 36, Rockefeller Archive Center, New York.
18. Gerard R. Pomerat diaries, entry 9 April 1949, RF, 12.2, Box 36, Rockefeller Archive Center, New York. For this reason Pomerat retrospectively characterized the negotiations 1946–47 as hampered by ‘constraint and hesitancy.’
19. Creager, ‘Tracing the Politics,’ 374.
20. ‘Work in radiobiology,’ Bohr in a characteristic passage explained to Pomerat as being of ‘great importance for a little country that has no intention of establishing an atomic energy commission.’ Gerard R. Pomerat diaries, entry 8 May 1947, RF, 12.2, Box 36, Rockefeller Archive Center, New York.
21. Koch, ‘Træk af et samarbejde,’ 302.
22. Anker Hansen, Industrial Attaché at the Danish Embassy in Washington, to the Danish Foreign Ministry in Copenhagen, 31 August 1955, box 170 ‘Atomenergiudvalget,’ the ATV archive, Erhvervsarkivet, Aarhus.
23. Anker Engelund, Chairman of ATV, to G. Hartz, 4 November 1955, Box 170, ‘Atomenergiudvalget,’ the ATV archive, Erhvervsarkivet, Aarhus. Also quoted in Nielsen et al., *Til samfundets tarv*, 34–5.
24. Nielsen et al., *Til Samfundets tarv*, 35–53, 81–8.
25. Minute of Bohr’s meeting with Strauss, 4 May 1955, the AEK archive, Rigsarkivet, Copenhagen.
26. The concept of transatlantic hegemony based on consensus is discussed in Krige, *American Hegemony* and Krige, ‘Atoms for Peace,’ 161–81.
27. USIS Copenhagen to USIA Washington, 12 August 1955, Lot 57D688, box 38, NA. Here quoted from Christensen, ‘Atoms for Peace & Pax Americana,’ 77.
28. USIS Copenhagen to USIA Washington, 12 August 1955, Lot 57D688, box 38, NA. Here quoted from Christensen, ‘Atoms for Peace & Pax Americana,’ 77.
29. USIS Copenhagen to USIA Washington, 20 April 1956, RG 306, box 4, NA. Here quoted from Christensen, ‘Atoms for Peace & Pax Americana,’ 78–9.
30. American Embassy Copenhagen to Dept. State, desp. 78 (Economic Review of Denmark – Second Quarter 1955), 27 July 1955, 859.00/7-2755, RG 59, NA. Here quoted from Christensen, ‘Atoms for Peace & Pax Americana,’ 82.
31. Christensen, ‘Atoms for Peace & Pax Americana,’ 57–62.
32. See for example Kampmann’s article ‘Videnskaben og samfundet’ in the Danish newspaper *Dagens Nyheder*, 25 November 1957.
33. Minute of meeting at the office of the Minister of State, 7 January 1955, Jn.1.1956, the AEK archive, Rigsarkivet, Copenhagen.
34. *Berlingske Tidende*, one of the leading Danish newspapers, on 10 June ran a conspicuous article on the front page, predicting that Denmark would have nuclear power stations within 10 years. Similar articles appeared in dozens of other Danish newspapers and magazines.
35. Forslag til lov om en atomenergikommission, *Folketingstidende 1955–56*, Tillæg A, spalte 635. See also Nielsen et al., *Til samfundets tarv*, 63.
36. Christiansen and Nørgaard, *Faste forhold, flygtige forbindelser*.

37. Minute of meeting at the office of the Minister of State, 7 January 1955, Jn.1.1956, the AEK Archive, Rigsarkivet, Copenhagen.
38. Petersen, *Atomalder uden kernekraft*, 88–9.
39. Minutes of AEK meeting, 27 May 1955, Jn. 15.1.55, the AEK archive, Rigsarkivet, Copenhagen. See also Nielsen et al., *Til samfundets tarv*, 48–53, and Christensen, 'Atoms for Peace & Pax Americana,' 70.
40. Knudsen, *Risøs reaktorer*, 27.
41. Facility in which the operator is protected from radiation by heavy walls and lead glass while able to manipulate highly radioactive material by means of remote controlled equipment.
42. The DKK 40 million in annual operating costs for Risø in 1963 amounted to roughly 15% of all grants allocated under the Danish appropriations act to research and education, see Knudsen, Nielsen, and Nielsen, 'From Private Philanthropy,' 418.
43. Nielsen et al., *Til samfundets tarv*, 74–8, 88–91.
44. A transnational approach to history does not eliminate nation states, but in fact preserves them as key analytical categories. Using concepts like 'circulation,' 'flow,' and 'connection,' it puts, however, national narratives in a new perspective. See Van der Vleuten, 'Towards a Transnational History,' 974–94.
45. Minutes of AEK meeting, 7 August 1956, the AEK archive, Rigsarkivet, Copenhagen. See also Nielsen et al., *Til samfundets tarv*, 81–6.
46. Minutes of AEK meeting, 20 April 1957. The AEK archive, Rigsarkivet, Copenhagen.
47. Robert Henriksen, Presidential speech in the Association of Danish Utilities, 11 June 1957, the AEK archive, Rigsarkivet, Copenhagen.
48. 'Tør ikke vente paa Atomreaktoren ved Roskilde,' *Roskilde Dagblad*, 18 May 1956.
49. Knudsen, 'En kerneforretning,' 82–5.
50. Edquist and Lundvall, 'Comparing the Danish and Swedish Systems,' 265–98.
51. Knudsen, 'Konsensus og konflikt,' 33–4 and 50.
52. The Danish electrification process is thoroughly treated in Van der Vleuten, 'Electrifying Denmark.'
53. Nothing like a detailed plan for Risø has ever been drafted, nor discussed in AEK. What comes closest is a four page note by Bjerge, dated December 1955. The note has the title: 'Nogle betragtninger over Atomenergikommissionens opgaver og dens praktiske tilrettelæggelse af arbejdet,' Jn.1.1956, the AEK archive, Rigsarkivet, Copenhagen. For more details, see Nielsen et al., *Til samfundets tarv*, 96–8.
54. Nielsen et al., *Til samfundets tarv*, 96–103.
55. That this informal procedure was standard practice during the first 15 years of Risø's existence has consistently been described by former department heads and other high ranking employees at Risø in interviews with the authors of Nielsen et al., *Til samfundets tarv*. Interviewees are: V. Haahr (27 August 1996), N. Hansen (27 August 1996), N.W. Holm (14 April 1997), H.B. Møller (15 May 1997), J. Rasmussen (23 October 1997), K. Singer (26 August 1997), C.F. Wandel (23 September 1996), P.L. Ølgaard (24 April 1997).
56. The Niels Arley case is particularly illuminating. Trained and employed at Copenhagen University, Arley became an expert in nuclear radiation and radiation protection. In 1957, after many visits to Norwegian and Swedish nuclear research facilities, he publicly criticized the Danish government's passiveness for many years with respect to nuclear energy research and AEK in particular for misleading the public with respect to Denmark's possibilities as a reactor exporting country. Instead, Arley proposed that AEK should spend most of its big budget on building an institute for doing research in radiation effects and radiation protection. AEK refused all Arley's claims and proposals, and soon Arley would find his career opportunities in Denmark completely blocked.
57. Ward P. Allen to Gerard Smith, 21 October 1955, Lot 57D688, box 402, NA. Here quoted from Christensen, 'Atoms for Peace & Pax Americana,' 83.
58. Nielsen et al., *Til samfundets tarv*, 106–10.
59. Nielsen and Wistoft, 'Painting Technological Progress,' 426–33; Knudsen, Nielsen, and Nielsen, 'From Private Philantropy,' 407–15.
60. Bush, *Science – The Endless Frontier*.
61. One example is Risø's measurement of the neutron lifetime, published in Christensen et al., 'Free-Neutron Beta-Decay Half-Life,' 1628–40, which for many years was considered the standard value.
62. Until it was closed down in 2000, the DR3 reactor and its cold neutron source ranked high among the official big-science laboratory facilities in Europe. Nielsen et al., *Til samfundets tarv*, 470–9.

63. Knudsen, ‘En kerneforretning,’ 95.
64. Nielsen et al., *Til samfundets tarv*, 161 and 562.
65. We have not found evidence proving that the Agricultural Department’s early and much publicized research in selective plant breeding and disease control actually produced results that were implemented in Danish agriculture at large. But the point here is that numerous newspaper articles claimed the agricultural research at Risø to be a great success.
66. The Calder Hall reactors provided power for the grid and plutonium for the UK nuclear weapons program.
67. The AGR (advanced gas-cooled reactor), the SGHWR (steam generating heavy water reactor), and the HTGR (high temperature gas cooled reactor) were all at various stages of development in the UK, a fact which contributed to the general opinion in AEK in the late 1950s and early 1960s that the UK was the world leader as far as civilian nuclear power was concerned.
68. Report by the Three Wise Men on Euratom, 4 May 1957, http://www.ena.lu/report_wise_men_euratom_1957-2-1281.pdf, 15. See also Krige, ‘The Peaceful Atom,’ 28–31.
69. The uncertainty concerning the future of nuclear power meant that AEK and Risø usually recommended Denmark’s participation in upcoming international nuclear development projects. As a member of OEEC’s European Nuclear Energy Agency (ENEA), Denmark in 1958 entered the European Eurochemic project, which aimed to construct a test station for reprocessing spent nuclear fuel in Mol, Belgium. In 1959 Denmark joined the Halden project (together with 11 OEEC countries) to gain experience with BWR-type reactors through systematic experiments with the Norwegian 20 MW reactor in Halden, Norway. And finally, in 1959 Demark joined the UK-initiated Dragon-project which aimed to test fuel and materials for the 20 MW HTGR to be inaugurated in 1962 in Winfrith, England. This type of reactor, operating with helium gas as coolant and graphite as moderator was believed by many reactor engineers to be a promising reactor for the future. Risø contributed to the project by irradiating fuel and other materials from Dragon in Risø’s largest experimental reactor DR3. According to Von Bülow, ‘Atomenergisamarbejdet i Europa,’ 138–43, Denmark’s financial contribution to the Eurochemic, Halden and Dragon projects amounted to about 4% of Risø’s yearly budget in the early 1960s, much less than was spent on Risø’s own DOR project. For more details on Denmark’s participation in Nordic nuclear organizations, see Marcus, *Half a Century of Nordic Nuclear Co-operation*.
70. A couple of years later, Risø discovered that variants of the DOR concept were, in fact, being studied by Euratom as well as the Canadian atomic energy authorities. *Risø Report* no. 17, 1960, 61–71.
71. DOR meeting no. 1, 4 September 1957. Minutes in the Risø archives, Risø National Laboratory. See also Nielsen et al., *Til samfundets tarv*, 103–4, 113–23.
72. Krige, ‘The Peaceful Atom,’ 30.
73. Hewlett and Holl, *Atoms for Peace and War*, 509.
74. Information from http://triga.ga.com/ (last accessed 17 February 2009).
75. O. Kofoed-Hansen, ‘Om Risøs forskningsplaner,’ undated letter in Risø’s management archive, Risø National Laboratory. Quoted in Nielsen et al., *Til samfundets tarv*, 119.
76. Danatom, ‘Memorandum om eventuel dansk industriel deltagelse i DOR-studiet,’ memorandum in the Risø archives. See also Nielsen et al., *Til samfundets tarv*, 120–1.
77. H. von Bülow, R. Kayser, and P.L. Ølgaard, ‘Bemærkninger til det af Danatoms sekretariat udarbejdede memorandum om dansk industriel deltagelse i DOR-studiet,’ 22 February 1962, the Risø archives, Rigsarkivet, Copenhagen. See also Nielsen et al., *Til samfundets tarv*, 121–2.
78. Editorial article in the utilities’ official journal, *Elektroteknikeren* (1963), 63.
79. Danish–Swedish agreement on nuclear cooperation of 7 January 1965. In Jn.5.80-10, the AEK archive, Rigsarkivet, Copenhagen.
80. The DK-400 project is discussed in detail in Nielsen et al., *Til samfundets tarv*, 168–82.
81. New Jersey Power and Light Company, ‘Report on Economic Analysis for Oyster Creek Nuclear Electric Generating Station,’ 1964.
82. This conclusion is drawn by Nielsen et al., *Til samfundets tarv*, 168–82. The conclusion is based upon a detailed study of all available material concerning the DK-400 project in the Risø archives, Rigsarkivet, Copenhagen.
83. Nielsen et al., *Til samfundets tarv*, 219–23.
84. The Danish nuclear power debate is treated in detail in Rasmussen, *Sære alliancer*, 123–64, and especially in Danielsen, *Atomkraften under pres*, 1–1063.
85. Press release from the Danish government, 10 August 1976.
86. Miljøstyrelsen, *Vurdering af elværkernes salthorstundersøgelse*.

87. 2. behandling af forslag til beslutning om offentlig energiplanlægning uden atomkraft, *Folketingstidende. Forhandlingerne*, 29 March 1985, columns 8254–62.
88. Forslag til lov om en atomenergikommission, *Folketingstidende* 1955–56, Tillæg A, spalte 635.
89. Nielsen, 'Risøs oprettelse og kamp,' 239–58.
90. Interview with Niels Hansen, 27 August 1996. Quoted in Nielsen et al., *Til samfundets tarv*, 159.
91. The history of Risø's Metallurgy Department is given in Nielsen et al., *Til samfundets tarv*, 183–96.
92. Nielsen et al., *Til samfundets tarv*, 160–4, 376–7.
93. Nielsen et al., *Til samfundets tarv*, 124–36.
94. Risø, '*Risø-Prøvestation for Vindmøller*,' 1.
95. Nuclear research centers in many other countries eventually also had to abandon nuclear power development as their main activity and switch to material research, environmental research or the like. This holds for example for Studsvik in Sweden and VTT in Finland. According to Heinonen and Rosenberg, 'Nuclear Research Centres,' Risø has managed to maintain a larger fraction of basic research than its Nordic sister institutions.

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