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The First Nuclear Industry: Radioisotopes, State and Society



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EXECUTIVE SUMMARY

This report has been conceived as a complement to the short national reports of the HONEST project. These reports deal with the history of nuclear infrastructures in different European countries, focusing on the social tensions that emerged around the setting up and the operation of nuclear reactors for the production of electricity. Nuclear technology was part of a larger network of military origin, which also included a civil branch devoted to the production and distribution of radioisotopes for research, medical and industrial uses.

Radioisotopes, as well as military uses of nuclear energy, crucially shaped the social responses to nuclear technology. In fact, the only non-military application of nuclear reactors between their creation (Fermi's Chicago pile, 1942) and the first commercial nuclear power reactor (Shippingport, 1957) was the production of radioisotopes. As the only real civil product of reactors, radioisotopes moulded early images of the nuclear, and helped to counteract military-related images, becoming essential resources for legitimising the nuclear sector.

The study of the history of radioisotope industry can help to understand continuities and discontinuities in the representations of nuclear energy, and their long term effects in shaping the image of atomic energy. In particular, we sought to understand how the rhetoric strategies developed in relation to radioisotopes were later to be used in the advertising of nuclear energy and in helping to build an image of a "clean" atomic energy.

This report is structured in three sections. In the first section, we present a general historical background narrative about the antecedents of radioisotope-related R&D before the Second World War and of the post-war developments leading to the establishment of a radioisotope industry. In this narrative, the focus will be on American developments, as the United States constitutes the most important player in the production of and the research with these materials. Indeed, these have been the developments that have received most attention in the historical literature.

The following section focuses on the history of European radioisotope industries. This part is the more innovative part of this report, as the history of European radioisotopes has never been studied comprehensively. We will approach this analysis from a comparative point of view, which will focus on four different countries: the United Kingdom, France, Germany and Spain. The choice of these countries is mainly based on the availability of historical secondary sources. In any case, these countries represent a good combination of major players of the radioisotope market (France and the UK), an important nation in the industrial uses of radioisotopes (Germany), which is at the same time politically interesting because of its Cold-War related political division, and finally a scientifically and politically "peripheral" actor (Spain), that can help to contrast with democratic countries. Unfortunately, we will leave out of our study some countries such as the Netherlands and Belgium, which became major players in the radioisotope market, as well as the Soviet Union/Russia and all East European bloc.

In each case, a description of main events in the development of radioisotope production and use is provided, as well as an analysis of the public perception based on the analysis of the press coverage of radioisotopes. This study is supplemented by an account of IAEA efforts in radioisotope research which can help to discuss transnational developments. The focus on the IAEA is based on the fact that the Agency became the main actor in the configuration of the field since the 1960s. Finally, the last section of the report provides a comparative analysis of the pattern of development of radioisotope industries and societies in Europe, allowing to empirically checking the basic hypothesis of this report.

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Abbreviations:

AEC	Atomic Energy Commission (United States)
AERE	Atomic Energy Research Establishment (United Kingdom)
CEA	Commissariat à l'Energie Atomique (French Nuclear Energy Board)
CNRS	Centre national de la recherche scientifique (National Center for Scientific Research, France)
DFG	Deutsche Forschungsgesellschaft (German Research Council)
EDF	Electricité de France (French National Company of Electricity)
EURATOM	European Atomic Energy Community
FAO	Food and Agriculture Organisation (United Nations)
FRG	Federal Republic of Germany
GDR	German Democratic Republic
IAEA	International Atomic Energy Agency
INH	Institut National d'Hygiène (French National Institute of Hygiene)
INRA	Institut national de la recherche agronomique (French National Institute for Research in Agronomy)
INSERM	Institut national de la santé et de la recherche médicale (French National Institute for Health and Medical Research)
ISO	International Organisation for Standardisation
JEN	Junta de Energía Nuclear (Spanish Nuclear Energy Board)
LSA	Laboratoire de synthèse atomique (Atomic Synthesis Laboratory, France)
LPPC	Laboratoire de physiologie et de physicochimie (Laboratory of Physiology and physico-chemistry, France)
ORIS	Office de rayonnements ionisants (CEA Office of ionizing rays)
PTBT	Partial Test Ban Treaty
SED	Sozialistische Einheitspartei Deutschlands (Socialist Unity Party of Germany)
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UKAEA	United Kingdom Atomic Energy Authority
WHO	World Health Organisation (United Nations)
WMO	World Meteorological Organisation
WNA	World Nuclear Association

1. The first nuclear industry: the rise of the isotope

Most debates on nuclear energy focus on energy supply, military uses and the risks for human health and the environment. The social perceptions, images and rhetoric and that shapes these debates is nonetheless the result of a long history in which other elements have played a major role. Here, our aim is to analyse the radioisotope industry (that is, the system allowing for the production and circulation of isotopes) as an element which was central to the shaping of the image of nuclear energy in the 1950s and 1960s and that, despite becoming less prominent in the recent decades, configured decisively the ways nuclear technology was conceived as *peaceful* and *useful* resource in contrast with its predominantly military uses.

Although technologically it is possible to produce radioisotopes without nuclear reactors (cyclotrons can be used to produce most isotopic species), the emergence of the radioisotope industry was tied to the establishment of nuclear programmes. Thus, radioisotope production was quite soon integrated in a system comprising uranium mining, enrichment and processing facilities, nuclear reactors, and plutonium separation plants, in which military uses had defined the contours. The participation of isotope research in this system was helped by the existence of health and safety divisions and by the notorious role physicists and other natural scientists had acquired in the nuclear projects.

Isotopes were also important for the emerging nuclear conglomerate as they provided its social legitimacy. Despite early promises about the use of the atom for producing electricity, the only non-military application of nuclear reactors between their creation (Fermi's Chicago pile, in 1942) and the first commercial nuclear power reactor (Shippingport, in 1957) was the production of radioisotopes. As the only real civil product of reactors, radioisotopes shaped early perceptions of the nuclear, and helped to counteract military-related images in public opinion nationally and internationally.

In the following sections, we aim to describe how this process of legitimation has operated in practice, describing the main actors and institutions for the implementation of isotope programmes, their goals and achievements. By comparing different national contexts and transnational exchanges, we aim to identify the main elements that facilitated or impeded the integration and support of radioisotopes in nuclear complexes, and show how, by establishment of international contacts, radioisotopes contributed to the shaping of these systems as well.

1.1. Isotopes before the Second World War

At its origin, the term isotope had a very technical meaning, denoting the different types of a chemical element which differ in neutron number. The name isotope (from the Greek “isos” (ἴσος "equal") and “topos” (τόπος "place"), implies that the different isotopes of an element occupy the same position on the periodic table. The hypothesis of the existence of isotopes was first formulated in 1912 by chemist Ernest Rutherford's former co-worker Frederick Soddy to explain the chemical inseparability of two radioactive elements, thorium (thorium-232) and “ionium” (today thorium-230), which displayed identical spectra.

The existence of isotopes was contested by many chemists until the early 1920s. However, Francis Aston's experiments with his mass spectrograph and, crucially, its reinterpretation in the framework of Soddy's hypothesis and Rutherford-Bohr atomic theory, made it essential to the new atomic paradigm in chemistry. In 1922, the scientific community confirmed the new consensus by awarding the Nobel prizes in physics and chemistry respectively to Niels Bohr and Francis Aston¹.

In the 1930s, isotope research had a major turning point with the invention of the cyclotron, an improved version of the particle accelerator developed by Ernest Lawrence at the Rad Lab at the University of California in Berkeley. By bombarding different materials with cyclotron-produced high energy beams, scientists could obtain small quantities of artificial radioactive isotopes, which soon were put into use for tracer experiments or in medicine². As example of these first experiences we can cite Rudolf Schoenheimer use light radioisotopes as molecular tracers in the University of Columbia³, or John Lawrence –brother of the inventor of the cyclotron- use of phosphorus-32 to treat leukaemia.

During the 1930s, Rad Lab produced radioisotopes were distributed to American and European laboratories via informal networks, helping to build an interdisciplinary and transnational community of researchers. In spite of the relevance of this research field –as measured by the number of Nobel Prizes awarded- the extent of these researches remained limited due to the small production capacities of cyclotrons.

¹ Jeff Hughes, “Making isotopes matter: Francis Aston and the mass-spectrograph”, *Dynamis* 29 (2009), 131-165.

² John L. Heilbron and Robert W. Seidel, *Lawrence and His Laboratory: A History of the Lawrence Berkeley Laboratory* (University of California Press, 1989).

³ Robert E. Kohler, Jr., “Rudolf Schoenheimer, isotopic tracers, and biochemistry in the 1930's”, *Historical Studies in the Physical Sciences* 8 (1977), 257-298.

1.2. Spreading isotopes: the distribution programmes

The invention of the first nuclear reactor as part of the Manhattan Project was a major breakthrough in the history of radioisotope production. Based on the stacking of concentrated fissionable uranium, it provided high neutron fluxes which could be used to trigger atomic transmutation and the production of radioisotopes from selected target materials⁴. Compared to the cyclotron, its major advantages were the possibility of continuous production of radioisotopes, a large diversification of products as well as the production of long lived radioisotopes, allowing wider distribution, also to more distant places.

After the war, the Atomic Energy Act put the Atomic Energy Commission (AEC) in charge of all nuclear activities in the United States. Most of the resources and efforts were of military nature, aimed at building a stockpile, and improve the yield and delivery capacity of nuclear weapons⁵. However, the need to justify such a massive investment before the public opinion and the congress led to the development of a civil branch that will explore the possibilities of nuclear energy production and the civil applications of radioisotopes, notably in biomedicine⁶.

The support of AEC to radioisotope techno-science materialised by the establishment of an isotope program in the new Oak Ridge facilities in January of 1946. Paul Aebersold, a former student of Ernest Lawrence in Berkeley Rad Lab, became the director, and launched an ambitious initiative to encourage scientists and physicians to use reactor-produced radioisotopes: the Isotope Distribution Program. A first shipment of carbon-14 was delivered to the Bernard Free Skin and Cancer Hospital in Saint Louis in August 1946, almost one year after the atomic bombing of Hiroshima. Since 1947, a regular service based at the Oak Ridge Isotope Division distributed radioisotopes free of production cost to American hospitals and laboratories, and, since 1948, actively promoted the training of scientists and physicians by means of courses at the Oak Ridge Institute of Nuclear Studies⁷.

⁴ On the invention of the nuclear reactor and its unintended economic consequences regarding property rights in its use of producing radioisotopes, see: Simone Turchetti, "A Contentious Business: Industrial Patents and the Production of Isotopes, 1930-1960", *Dynamis* 29 (2009), 191-217.

⁵ On the history of the AEC, see Richard G. Hewlett, and Oscar E. Anderson, *A History of the US Atomic Energy Commission. Vol. 1-3*. (National Technical Information Service, 1962-1987).

⁶ Timothy Lenoir and Marguerite Hays, "The Manhattan Project for Biomedicine", in: *Controlling Our Destinies*, ed. by Philip R. Sloan (University of Notre Dame Press, 2000), 19-46. The history of the use of radioisotopes in research and medicine has been extensively in Angela Creager *Life Atomic* (University of Chicago Press, 2013).

⁷ Néstor Herran, "Isotope networks: Training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306; Simone Turchetti, "For slow neutrons, slow pay: Enrico Fermi's patent and the U.S. atomic energy program, 1938-1953", *Isis* 97/1 (2006), 1-27.

These early initiatives to promote the use of radioisotopes were nonetheless limited because of national security considerations aimed to protect the American monopoly of nuclear military technology. Thus, severe restrictions for the export of radioisotopes were put in place, and foreign researchers were not allowed to attend Oak Ridge courses until 1949 and, afterwards, the access was strictly controlled⁸. However, the difficulties to obtain radioisotopes were countered by the emergence of nuclear programmes in other countries. In particular, the United Kingdom turned into a major supplier of radioisotopes for European laboratories and hospitals and its training facilities became the mecca of the emerging community of nuclear engineers⁹.

1.3. Atoms for Peace and the rise of the radioisotope industry

The Atoms for Peace initiative, launched by US president Dwight Eisenhower in 1953, opened a new scenario for the development of nuclear technology and indeed for the radioisotope industry. In the absence of operational nuclear electric power plants, radioisotopes became a key element for displaying the possibilities of nuclear energy. The international exchange of nuclear materials and expertise via bilateral agreement between the United States and other countries became a diplomatic tool in the exercise of soft power¹⁰. The start of nuclear programmes in many countries implied on a regular basis the establishment of research centres on radioisotope techniques, and the setting up of research reactors was accompanied by the isotope production too. Obligated by the clauses of bilateral agreements or by a desire to control the dissemination of nuclear products, the distribution of radioisotopes was generally put under state monopoly or under the supervision of regulatory commissions.

The availability of radioisotopes brought important transformations in biomedicine and other sciences. Either as research tools or research-enabling technologies, isotopes were crucial elements in the reconfiguration of scientific disciplines and interdisciplinary relationships after WWII, playing a particularly relevant role in the rise of such disciplines as molecular biology¹¹.

⁸ Angela Creager, "Tracing the politics of changing postwar research practices: the export of 'American' radioisotopes to European biologists," *Studies in History and Philosophy of Biological and Biomedical Sciences* 33 (2002), 367-388.

⁹ This question is treated in more detail in the section devoted to the British radioisotope industry in this report. See also: Néstor Herran, "Spreading Nucleonics: the Isotope School at the Atomic Energy Research Establishment, 1951-1967," *British Journal of the History of Science* 39/4 (2006), 569-586.

¹⁰ John Krige, "Techno-Utopian Dreams, Techno-Political Realities: The Education of Desire for the Peaceful Atom", in *Utopia-Dystopia: Conditions of Historical Possibility*, ed. by Michael D. Gordin and Helen Tilley (Princeton University Press, 2010), pp. 151-75; John Krige, "Atoms for Peace, Scientific Internationalism, and Scientific Intelligence", *Osiris* 21 (2006), 161-81. See also: John Krige, "The Politics of Phosphorus-32: A Cold War Fable based on Fact," *Historical Studies in the Physical Sciences* 36 (2005), 71-91.

¹¹ Bruno Strasser, *La fabrique d'une nouvelle science: la biologie moléculaire à l'âge atomique, 1945-1964* (Leo S. Olschki, 2006)

By establishing radioactive tracers as a general research tool, researchers gained access to a more holistic vision of the body, with new insights into the functioning of all sorts of organs, embedded in a complex equilibrium, and indeed to new perspectives of the environment, brought about by the use of radioisotopes as global environmental tracers in climatology, oceanography and the Earth sciences¹².

In the late 1950s and early 1960s, industrial uses of radioisotopes were considered a logic direction for the expansion of the applications of isotopes. The UNESCO played an important role in setting up the field, by organising conferences in Paris (1957) and Copenhagen (1960)¹³, but the International Atomic Energy Agency, founded in 1957, soon took the initiative, and became the driving force in the promotion of radioisotopes in industry and agriculture, a task that was facilitated by the standardisation of instruments, units and experimental protocols. In the 1960, as a collateral effect of the controversy about the health effects of the fallout from nuclear tests, there was a surge of interest on the effects of radioactivity in the human body¹⁴. Epidemiological research such as the long-term study on the victims of Hiroshima by the Atomic Bomb Casualty Commission, and discussions on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) put the basis of the linear no-threshold model used for preventing damage by ionising radiations¹⁵. Safety regulations were implemented in nuclear programmes and generally in all activities making use of radioactive isotopes, limiting the widespread use of this technology.

Safety regulations had also a major role in the most important development regarding the use of isotopes in medicine. As Angela Creager as shown, as early as in the 1960s the medical

¹² Ronald Rainger, "A wonderful oceanographic tool: The atomic bomb, radioactivity and the development of American oceanography," in Helen Rozwadowski and David Van Keuren (eds.), *The machine in Neptune's garden: Historical perspectives on technology and the marine environment* (Science History Publications, 2004), 93-131; Jacob Hamblin, *Oceanographers and the Cold War: Disciples of marine science* (University of Washington Press, 2005); Ronald Doel, "Constituting the postwar earth sciences: The military's influence on the environmental sciences in the USA after 1945," *Social Studies of Science* 33/5 (2003), 635-666. Jacob Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford University Press, 2013); Simone Turchetti, and Peder Roberts, eds., *The Surveillance Imperative: Geosciences during the Cold War and Beyond* (Palgrave Macmillan, 2014). The press also started to address the dangers of radioactivity: "Le danger atomique," *Le Monde*, 30.04.1954.

¹³ See, for example, the special issue devoted to the social and economic aspects of isotopes in the UNESCO magazine *Impact: science et société* 8/4 (1957).

¹⁴ The controversy was triggered by the contamination of fish and sailors of the "Lucky Dragon" Japanese boat. See: Toshihiro Higuchi, 'Radioactive Fallout, the Politics of Risk, and the Making of a Global Environmental Crisis, 1954–1963' (Georgetown University, 2011); Soraya Boudia, "Naissance, extinction et rebonds d'une controverse scientifique : by US nuclear test in the Marshall Islands. Les dangers de la radioactivité pendant la guerre froide," *Mil Neuf Cent. Revue d'histoire intellectuelle* 25 (2007), 157-70.

¹⁵ On the Atomic Bomb Casualty Commission, see: Susan Lindee, *Suffering Made Real: American Science and the Survivors at Hiroshima* (University of Chicago Press, 1994). On the UNSCEAR, see: Néstor Herran, "'Unscare' and Conceal: The United Nations Scientific Committee on the Effects of Atomic Radiation and the Origin of International Radiation Monitoring", in: *The Surveillance Imperative: Geosciences during the Cold War and Beyond*, ed. by Simone Turchetti and Peder Roberts (Palgrave Macmillan, 2014), 69–84.

community became to be aware of the disappointing results of the use of radioisotopes in the treatment of cancer. However, tracer methods based on radioisotopes produced important advances in diagnosis and, combined with improved imaging technology, provided crucial data on the biochemical pathways of organic substances in the human body¹⁶.

A specific isotope, the technetium-99, became especially appropriate for these uses. First developed by Powell Richards in the Brookhaven National Laboratory in 1958, the invention of the Mo-99/Tc-99 generator by his colleagues Walter Tucker and Margaret Greene provided a durable and easily transportable kit that allowed good-quality tracing by reducing considerably the dose of radiation absorbed by the patients. By the 1970s technetium-99m had become the ubiquitous in medical diagnostics because its emission profile, which could be detected efficiently by scintillation-based detection systems such as the Anger camera, and its short half-life, which significantly diminished patients exposure to irradiation¹⁷.

1.4. Radioisotopes after the Cold War

The last decades of the 20th century was a period of normalisation of the uses of radioisotopes, which become standard instruments in scientific laboratories, but a regression of their industrial uses. State support dwindled and, despite state-funded research reactors continued to provide most of basic irradiated materials, private companies assumed the distribution tasks. A globalised market emerged, controlled by a few companies working around a smaller catalogue of substances, with technetium-99 concentrating more than 80% of the uses in nuclear medicine. Over 10,000 hospitals use on a routine basis radioisotopes in radiotherapy and diagnosis with over 30 million patients each year.

In the late 2000s, the concentration of the global production of key radioisotopes put the isotope market in a fragile situation. As may be seen in table 1, most reactors producing radioisotopes for medicine are old and prone to unforeseen failures, or they require regular important maintenance phases. Amongst these reactors, some shall be shut down for security reasons in the very near future.

¹⁶ Angela Creager *Life Atomic* (University of Chicago Press, 2013), chapter eight.

¹⁷ The Brookhaven Laboratory distributed generators until 1965, when commercial distributors such as Nuclear Consultants (later taken over by Mallinckrodt) and Union Carbide Nuclear Corporation.

Name of reactor	Country	Year entry into service	Power	Targets	% of world production
NRU	Canada	1957	135 MW	HEU	50
HFR	Netherlands	1961	45 MW	HEU*	30
BR2	Belgium	1961	100 MW	HEU*	3
SAFARI	South Africa	1965	20 MW	HEU-LEU*	3
OSIRIS	France	1966	70 MW	HEU	3

Table 1: Most important reactors in 2014 producing radioisotope ⁹⁹Mo. 90% of world production relies on five old reactors, all being highly-enriched uranium (HEU) targets. The *-symbol indicates that conversion to low enriched uranium targets is underway¹⁸.

In 2007, the largest isotope producer, the NRU reactor in Canada, had to shut down for security reasons. However, because very few reactors produce today the vast majorities of isotopes used on a daily basis worldwide in medicine, especially in the imaging sector, politics have stepped in at several occasions in order to prevent planned shutdowns for security reasons, either arguing that the medical benefits of radioisotopes largely outweigh the risks or referring to the systemic importance of some of the reactors. Although at least in part foreseeable, this was the case in Canada in 2007 and again in 2009, when NRU received each time the right again, after many months of shutdown, to continue production¹⁹. The 2009 leak at the Chalk River reactor had provoked the imaging sector to use out-dated methods due to the lack of isotopes since at the time NRU covered almost 40% of the worldwide isotope demand²⁰. The crisis was made even worse by a planned maintenance shutdown of six months of the isotope-producing reactor in the Netherlands, followed by its forced shutdown for six months in 2010 due to a leakage. The initial complete shutdown deadline for NRU was October 2016, yet with no alternative in sight before 2018, NRU will stay up and running for the next years.

In the following sections we will explore some developments in European countries that contributed to this situation and, in general, to the creation and globalisation of the radioisotope market. Particular attention will be paid to the efforts of different nuclear establishments to promote and advertise radioisotopes as important and socially relevant applications of nuclear energy and how these activities contributed to the legitimisation of the whole nuclear sector.

¹⁸ European Observatory on the Supply of Medical Radioisotopes, *WG4 Report* (2014)

¹⁹ Hervé Morin, "L'imagerie médicale en panne, faute d'isotopes," *Le Monde*, 24.08.2009 ; see also: Anne Pélouas, "Les défaillances du Canada, principal producteur d'isotopes médicaux," *Le Monde*, 24.08.2009.

²⁰ "L'arrêt d'un réacteur canadien cause une pénurie d'isotopes médicaux," *Le Monde*, 14.08.2009.

2. National case studies

This section is organised around four national case studies, concerning some countries relevant for the development of the radioisotopes industry in Europe, and presenting interesting interactions between society and techno-scientific developments in the field: the United Kingdom, France, Germany and Spain. In addition, a final section is devoted to the analysis of transnational developments through the study of IAEA activities in the field of radioisotopes.

2.1. United Kingdom: Europe's major producer

Since the establishment of its nuclear program, the United Kingdom became the leading country in the development of the isotope industry in Europe. In the 1950s, Harwell's division of isotopes furnished most of the radioisotopes consumed in Western Europe, and in the 1960s the company Amersham became one of most important players in the increasingly globalised market of radioisotopes. After the privatisation of Amersham in 1981, the British case illustrates interesting dynamics regarding the public and private development of radioisotope applications, as well as the changing image of these scientific objects in public opinion.

2.1.1. Radioactivity and isotopes in the UK before WW2

Together with France, the United Kingdom was the place of the most important developments in radioactive research in the early 20th century. Ernest Rutherford put together in Manchester and Cambridge the theory of atomic disintegration, and his colleague Frederick Soddy first proposed the concept of isotope. In the early 1920s, the development of the mass spectrometer by Francis William Aston put this concept on solid experimental ground. The use of isotopes in research was also inaugurated in Rutherford's laboratory, where George Hevesy developed the method of radioactive tracers by studying the chemical separation of lead isotopes²¹.

The application of radioactivity to medicine was a major incentive for research and production of radioelements, as evidenced by the numerous articles in *The Lancet* featuring the use of radium in therapy. Demand for radium led to industrial developments, such as the establishment of the first radium factory in 1910 by the British Radium Corporation, and the creation a year later of

²¹ László Kovács & László Kovács Jr., *George de Hevesy* (Berzsenyi College, 2000).

the Radium Works Corporation. However, both initiatives were short lived, and did not survive the competition of American or Belgian radium in the 1920s²².

During World War 2, British nuclear experts tried to implement a programme to build an atomic bomb, but war restrictions led the leading staff to be transferred to Canada and the United States, contributing to the Manhattan project. In Britain, industrial installations were built in Amersham to produce radium bromide to be used in luminescent painting from German requisitioned radium-containing minerals. As we will see, the facilities run by the company Thorium Ltd. in Amersham were instrumental after the war in the emergence of the British radioisotope industry²³.

2.1.2. Isotopes in the British nuclear programme

The United Kingdom Atomic Energy Research Establishment (AERE), initially directed by John Cockcroft, was established in 1946. The facilities were established in Harwell, a former Royal Air Force station. Counting on strong support from the direction, the Isotope Division was created in 1948, just after the construction of the first British experimental reactor, GLEEP. It was charged with research on radioisotope techniques and the promotion of its application in biomedicine and industry²⁴.

Under the charismatic leadership of chemist Henry Seligman, Harwell's Isotope Division developed an extremely efficient service that arrived to compete with its American counterpart. The system was based on a division of work between the AERE production facilities at Harwell, charged with production in experimental reactors, and the radiochemistry centre, grounded on Thorium Ltd. site in Amersham, which was in charge of the distribution. The de-facto American embargo of isotopes for European laboratories in the late 1940s and early 1950s was an advantage for the British service, which became the main provider of radioisotopes to European laboratories²⁵.

The sale of isotopes (see figure 1) was coupled with an active promotion of radioisotope techniques among scientists by means of the establishment of the Isotope School in 1951,

²² David I. Harvie, 'The Radium Century', *Endeavour* 23/3 (1999), 100-105.

²³ Michael Feld & Michel De Roo, *History of Nuclear Medicine in Europe* (Schattauer, 2003).

²⁴ On the history of the British nuclear programme, see: Margaret Gowing and Lorna Arnold, *Independence and Deterrence*. Vols. 1 & 2. (Palgrave Macmillan, 1974); Tony Hall, *Nuclear Politics: The History of Nuclear Power in Britain* (Penguin, 1986); and Roger Williams, *The nuclear power decisions: British policies, 1953-78* (Taylor & Francis, 1980).

²⁵ Alison Kraft, 'Between medicine and industry: medical physics and the rise of the radioisotope, 1945-1965', *Contemporary British History* 20 (2006), 1-35.

which offered 3- or 6-week courses on radioisotope techniques. The Isotope School became the leading training facility in Europe, hosting until its closure in 1967 around two hundred courses which were attended by more than four thousand students from more than fifty countries.²⁶

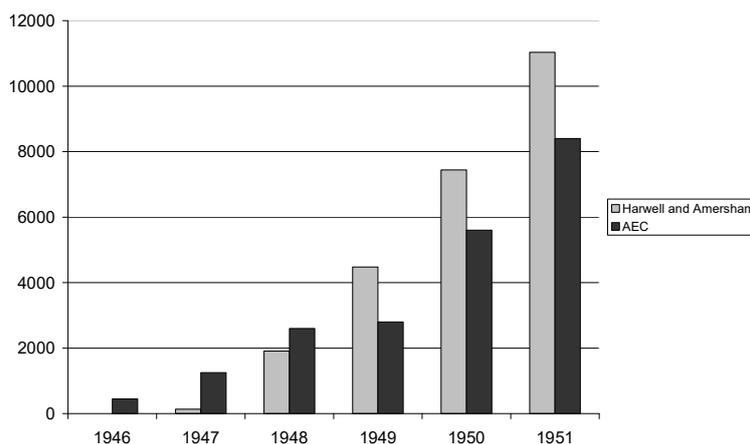


Figure 1: Radioisotope shipments sent by AEC and Harwell/Amersham, 1946-1951²⁷

The promotional activities of the AERE Isotope division not only aimed at medical and research uses, but had as an objective the development of an industrial market for radioisotopes. The use of heavy radioisotopes for the elimination of static electricity, the production of beta thickness gauges was developed and promoted before industrial associations and exhibitions²⁸. However, as shown in the internal reports of the isotope division, industrialists were reluctant to perform tracer experiments because of the cost of laboratories, lack of personnel familiar with radioactive techniques and suspicions about safety. To counteract this opposition, the AERE Isotope Division created specific courses, published technical monographs and health manuals for industrial users, designed simplified counting apparatus at reduced prices for industrial scientists. Indeed, an Isotope Advisory Service was established at Harwell, aimed at advising industry on the uses of isotopes and carrying out experiments for them. By 1951, approximately 500 firms had used the service and more than a hundred experiments had been performed. Contact with industrialists through the service also helped to recognise common problems to a

²⁶ Néstor Herran, 'Spreading Nucleonics: The Isotope School at the Atomic Energy Research Establishment, 1951-67', *British Journal for the History of Science* 39 (2006), 569-86.

²⁷ *Ibid.*, on p. 574.

²⁸ Henry Seligman. *Isotope Division 1948-1951. A true report of its failures and successes.* November 27, 1951. UK National Archives. File 6/657.

number of industries and to develop new nucleonic gadgets to solve them. By 1956, industrial research was a daily activity in the increased Isotope Division, with 800 enquiries per year.



Figure 2: Uses of radioisotopes in industry: gamma-radiography
(Source: IAEA archives, ref. AJ 6615c, © UKAEA)

These activities, focused on specific users, were complemented with broad dissemination of the beneficial uses of radioisotopes, using conferences, press releases, exhibitions and film. In a period during which no nuclear power plants were built, radioisotopes appeared as the only tangible outcome of the nuclear programmes and their utility was stressed to the point that they became the main shop window of the AERE. In 1956, just after the opening of the first British nuclear power plant, Seligman still argued that radioisotopes “may be regarded by future generations as the greatest contribution that the atomic age has made to mankind”²⁹.

2.1.3. Isotopes and industry in the 1960s and 1970s

By 1957, British yearly sales of isotopes attained 1 million pounds, most of them for medical use (50%), but with a considerable amount aimed at research (35%) and industrial applications (15%). However, the development of Calder Hall and other nuclear power plants shifted the focus of the AERE, and the promotion of isotope research suffered accordingly. Funds for isotope research were limited to the 7.25 per cent of the income generated by sales of radioisotopes, and UKAEA administrators exerted pressure for increases in Isotope School

²⁹ Henry Seligman, “Calder Hall Supplement”, *The Times*, 17 October 1956, xi.

student fees, arguing that they only recovered about 60 per cent of the expenses. Henry Seligman was increasingly dissatisfied with this situation and decided to move to Vienna to become IAEA deputy director general for research and isotopes³⁰.

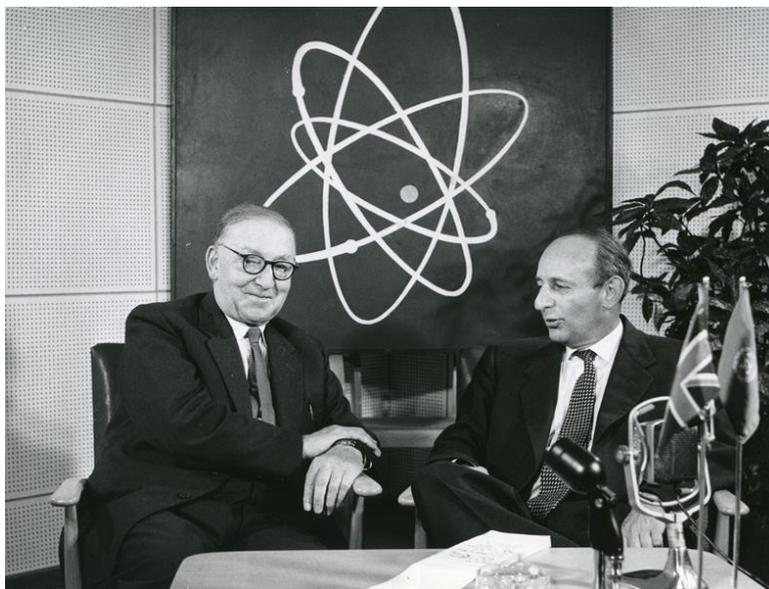


Figure 3: John Cockcroft and Henry Seligman at IAEA, September 1959
(Source: IAEA archives, ref. A-5131)

The Amersham Radiochemical Centre, directed by Patrick Grove, took over isotope production at Harwell, opening dedicated facilities for isotope production. In 1960, it increased most notably its catalogue of products by adding organic compounds radiolabelled with carbon-14 for biomedical research. For its part, the Isotope Division engaged in an active promotion of the application of radioisotope techniques in industry, such as static elimination or non-destructive testing. Dissemination activities, including documentaries and press releases, were also a main activity of the division, as well as coordination with national and international organisations, such as worker's unions, the WHO, the FAO or the IAEA³¹.

2.1.4. Amersham and the globalised market of nuclear medicine

In the mid-1960s, the expansion of the use of technetium 99m in nuclear medicine led to a major change of the radioisotope market. Developed in Brookhaven Laboratory, the technique was adopted in the UK in the 1960s, thanks to the availability of a high-flux nuclear reactor at

³⁰ Néstor Herran, 'Spreading Nucleonics: The Isotope School at the Atomic Energy Research Establishment, 1951–67', *British Journal for the History of Science*, 39 (2006), 569–86.

³¹ *Ibid.*

Harwell³². In 1966, Amersham counted 450 employees, over 2000 catalogue items and 20,000 users throughout the world, with isotope-related sales amounting to £1.9 million. This solid commercial basis permitted the increase of production and indeed the expansion of the range of available techniques by means of a dedicated cyclotron³³.

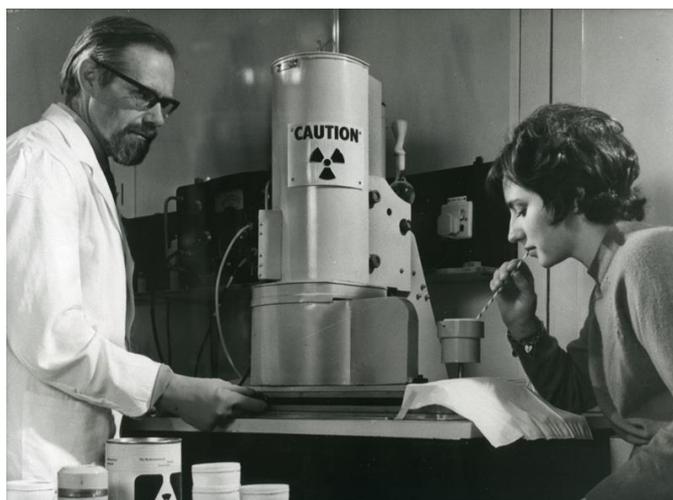


Figure 4: Uses of radioisotopes in medicine at Edinburgh Royal Infirmary
(Source: IAEA archives, ref. AJ 6266c, © UKAEA)

In the 1970s, Amersham continued its expansion in terms of sales and staff, passing from £6 million in sales in 1971 (62% from export of radioisotopes) to over £80 million in 1981 (80% from exports), employing as much as 2000 people. The healthy state of the company, with profit margins around 20%, made Amersham the first candidate for the process of privatisation first introduced during the first Margaret Thatcher government. Sold for £71 million in 1981, it became Amersham international in 1982 and continued its growth and internationalisation to become one of the major players of the global radioisotope market³⁴. After a series of merges, notably with Norwegian pharma company Nycomed, it was acquired in 2003 by General Electric for £5700 million, and is currently one of the major branches of GE Healthcare.³⁵

³² Christopher H. Green, 'Technetium-99m production issues in the United Kingdom', *Journal of Medical Physics* 37/2 (2012), 66-71.

³³ Walter C. Patterson, *Going Critical: An Unofficial History of British Nuclear Power* (Palladin, 1985)

³⁴ David Parker, *The Official History of Privatisation Vol. I: The formative years 1970-1987* (Routledge, 2009).

³⁵ Mark Tran, "Amersham agrees to £5.7bn takeover", *The Guardian*, 10 October 2003.

2.2. France: building on the radium's heritage

France, counting after the Second World War on the expertise of its scientific community and a mature radium industry, was one of the first European countries to develop a nuclear programme. The French *Commissariat à l'Énergie Atomique* (CEA) –the equivalent of the Atomic Energy Commission- was established in October 18, 1945, under the direction of Frédéric Joliot-Curie and became a leader in the promotion of peaceful uses of radioactivity. The study of CEA's activities regarding radioisotopes is a clear example of an active promotion of the applications of nuclear energy by the state, which led to the building up of a strong research community and helped to legitimise nuclear energy since the first stages of the French national nuclear programme.

2.2.1. Nuclear research in France prior to the Cold War

As the birthplace of radioactivity research³⁶, France was one of the first European countries to establish an industry based on radioactive substances, and particularly on the medical use of radium³⁷. In the 1930s, Frédéric Joliot and Irène Curie discovered artificial radioactivity³⁸, opening the way to the production of radioisotopes.

In 1940, the cyclotron installed at the basement of the Collège de France in Paris by Frédéric Joliot with the financial support of the Rockefeller Foundation and CNRS, was used to produce radioisotopes. This development was accompanied by the creation of the *Laboratoire de synthèse atomique* (LSA) in Ivry-sur-Seine near Paris, equipped with a Van de Graaf accelerator, which received visits of pioneering figures in radioisotope research, such as the chemist Georg von Hevesy³⁹. Joliot's group counted with an important support from the French government, his group receiving approximately two percent of all French research budget⁴⁰.

³⁶ For a brief chronology, see: Yves Cohen, "Centenaire Becquerel: Les grandes étapes de la découverte et de l'utilisation des radioéléments (1896-1996)," *Revue d'histoire de la pharmacie* 316 (1997), 415-422.

³⁷ See, for example: Paul-Marie de La Gorce, *L'aventure de l'atome*, 2 vols., (Flammarion, 1992). On the early history of the radium industry in France, see Soraya Boudia, *Marie Curie et son laboratoire: sciences et industrie de la radioactivité en France* (Archives Contemporaines, 2001).

³⁸ For an introduction, see chapter 12 in: Adrian Thomas and Arpan Banerjee, *The History of Radiology* (Oxford University Press, 2013).

³⁹ Jean-François Picard, "Physique des rayonnements et sciences du vivant: Le CEA et la recherche biomédicale, un aperçu historique," *médecine/sciences* 32 (2016), 634-639, here 635. For a detailed technical history of French accelerators and research reactors, see: Matthew Adamson, "Cores of production: Reactors and radioisotopes in France," *Dynamis* 29 (2009), 261-284.

⁴⁰ See Dominique Pestre, *Physique et physiciens en France (1918-1940)* (Editions des Archives contemporaines, 1984). Spencer Weart estimates that amongst all scientific articles published in 1939 on nuclear fission, 40% are produced by American researchers, followed by France with 25% before Germany and the UK: Spencer Weart, *Scientists in Power* (Harvard University Press, 1979).

Although the subsequent German occupation limited French research efforts, the last years of the War saw an important revival, with Joliot who had stayed in France relaunching radioisotope research at the LSA.

2.2.2. The CEA and the rise of 'atomic medicine', 1945-1960

The early post-war period was also a period of scientific exchange and significant reorganisation, marked by the rapid rise of the use of radioisotopes in biology, medicine and related fields, a development that may only be compared to parallel efforts in the United Kingdom and in the United States. Moreover, as in the case of all emerging nuclear powers⁴¹, transnational exchanges as well as the construction of "hybrid knowledge" were vital for these developments. As historian Jean-Paul Gaudillière has shown, pre-existent transnational networks were of great importance in establishing post-war biomedical isotope research in Europe, by establishing a network of exchange of personnel, technologies and information⁴². In the case of France, the United States served as a model for many of the new possibilities. As early as 1945, a French government mission was sent to the United States in order to collect as much information as possible on the nascent US biomedical scene, in particular on advances during wartime research, and to establish contacts with relevant research institutes, as well as gather names of instrument makers and companies that could supply research material and instrumentation.

In post-war France, still marked by frequent electricity cuts and rationing programs, mainly two research institutions, the French *Institut National d'Hygiène* (INH) –the local equivalent of the National Institute of Health with Louis Bugnard as its director–, and the CEA steered the production and circulation of radioisotopes during the first decades after the war, thus actively shaping the rise of biomedicine.

At the INH, created already under the Vichy government in 1941, Louis Bugnard promoted cooperation as well as scientific and technological transfers, first and foremost between France and the United States. One main reason was that French-produced radioisotopes were at this early stage still rare and not available to researchers outside of the closed circle of the *Institut*

⁴¹ See Gabrielle Hecht, *Being Nuclear: Africans and the Global Uranium Trade* (MIT Press, 2012); John Krige, "Hybrid knowledge: the transnational co-production of the gas centrifuge for uranium enrichment in the 1960s," *British Journal for the History of Science* 45/3 (2012), 337-358.

⁴² Jean-Paul Gaudillière, "Normal Pathways: Controlling Isotopes and Building Biomedical Research in Postwar France," *Journal of the History of Biology* 39 (2006), 737-764.

de Radium, namely Robert Courier and Antoine Lacassagne⁴³. Indeed, the radioisotopes produced by Joliot's cyclotron at the Collège de France in Paris went exclusively to the *Institut de radium*. Bugnard's strategy was therefore to put in place scientific and industrial exchanges, in particular with the United States, in order to secure supply, instrumentation, as well as know-how. The radioactive laboratory which he set up at Necker, the Sick Children's Hospital in Paris, relied heavily on these exchanges and it was the first centre for promoting the use of radioisotopes in medical research in France. Key personnel received training in the US and grants were secured to buy the necessary machinery. In the early 1950s, Kodak was initially solicited for the supply of radioisotopes, but as historian Angela Creager has shown, a virtual embargo based on national security considerations was put in place⁴⁴. Permits were cumbersome to obtain and, as a result, the French turned to the United Kingdom, where radioisotopes produced at Harwell could be obtained without having to comply with time-consuming administrative procedures⁴⁵.

Radioisotopes transformed French clinical research, with priority given in consequence to biology and experimental medicine, most notably tracer-based study of metabolisms and molecular processes. At the CEA Frédéric Joliot-Curie oversaw as his first action the construction of the ZOE experimental reactor at the Fort Châtillon, just outside of Paris, which was put into service in 1949⁴⁶. The focus on research and isotope production reflected the desire of Joliot-Curie to underplay the military component of nuclear research at the CEA. However, this goal could not solely be achieved by implementing a transnational strategy of cooperation as pursued at INH under Bugnard, but should imply building a strong, independent nuclear complex in the long French tradition of radium and cancer research, as exemplified by Marie Curie's undertakings⁴⁷. CEA's first focus was therefore on radiotherapy and later, during the second half of the 1950s, it developed its own biological research infrastructure⁴⁸.

⁴³ Ibid., 742.

⁴⁴ Angela Creager, "Tracing the politics of changing postwar research practices: the export of 'American' radioisotopes to European biologists," *Studies in History and Philosophy of Biological and Biomedical Sciences* 33 (2002), 367-388; Angela Creager, "Nuclear Energy in the Service of Biomedicine: The U.S. Atomic Energy Commission's Radioisotope Program, 1946-1950," *Journal of the History of Biology* 39 (2006), 649-684; see also: John Krige, "The Politics of Phosphorus-32: A Cold War Fable based on Fact," *Historical Studies in the Physical Sciences* 36 (2005), 71-91.

⁴⁵ Between October 1949 and April 1952, French laboratories imported 1161 radioactive sources from Harwell and only 30 sources from Oak Ridge, see: CEA report AN-CAC, SAN 71471, cited in Gaudillière, (2006). See also: Nestor Herran, "Isotope networks: Training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306.

⁴⁶ Matthew Adamson, "Cores of production: Reactors and radioisotopes in France," *Dynamis* 29 (2009), 269.

⁴⁷ Jean-Paul Gaudillière, "Normal Pathways: Controlling Isotopes and Building Biomedical Research in Postwar France," *Journal of the History of Biology* 39 (2006), 740.

⁴⁸ On the history of CEA, see: François Jacq, *Pratiques scientifiques, formes d'organisation et représentations politiques de la science dans la France de l'Après-guerre*, unpublished PhD manuscript, (Ecole nationale des Mines de Paris,

By 1954, two reactors produced radioisotopes in France, allowing local supply for medicine and research. By the mid-1950s, radioisotope import ratios had shifted from 3 to 1 (units imported versus units produced in France) to 1:2. By 1960, CEA's reactors satisfied 90% of the national demand, and a 30% of its production was exported (see figure 5 for an overview and figure 6 for comparison)⁴⁹. The use of radioisotopes for fundamental research was encouraged by the CEA, which in 1952 established a biology section headed by Jean Coursaget, a protégé of Bugnard's.

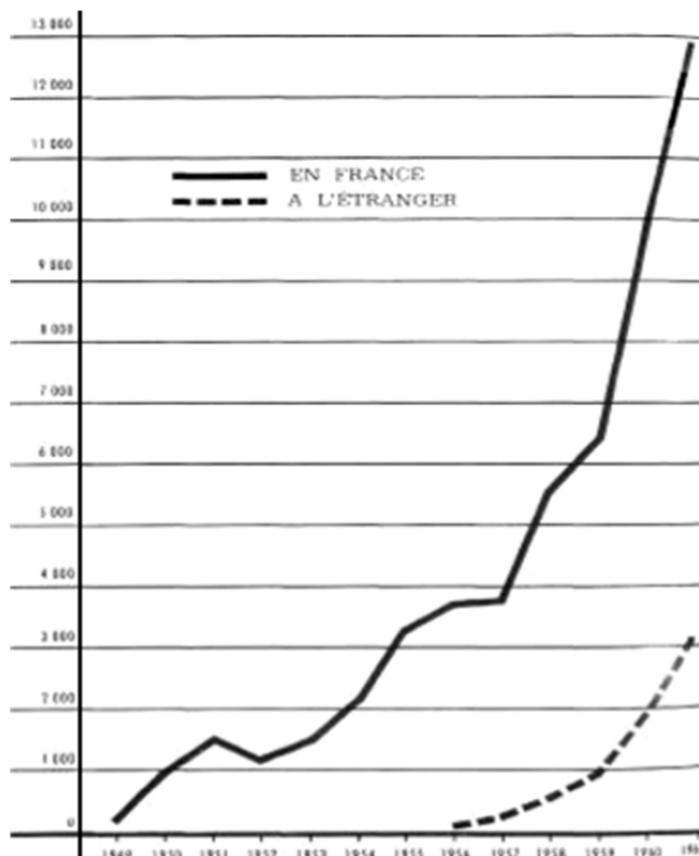


Figure 5: Number of radioisotope shipments (from 0 to 13000) within France and to foreign countries between 1949 and 1961. For comparison, the AEC made between 1946 and 1955 around 64,000 shipments.⁵⁰

1996). For a concise introduction, see: Jean-François Picard, "Physique des rayonnements et science du vivant. Le CEA et la recherche biomédicale, aperçu historique," *médecine/sciences* 32/6-7 (2016), 634-639.

⁴⁹ Jean-Paul Gaudillière, "Normal Pathways: Controlling Isotopes and Building Biomedical Research in Postwar France," *Journal of the History of Biology* 39 (2006), 747.

⁵⁰ "Radioisotopes 'economy of promises': On the limits of biomedicine in public legitimization of nuclear activities," *Dynamis* 29 (2009), 241-259.

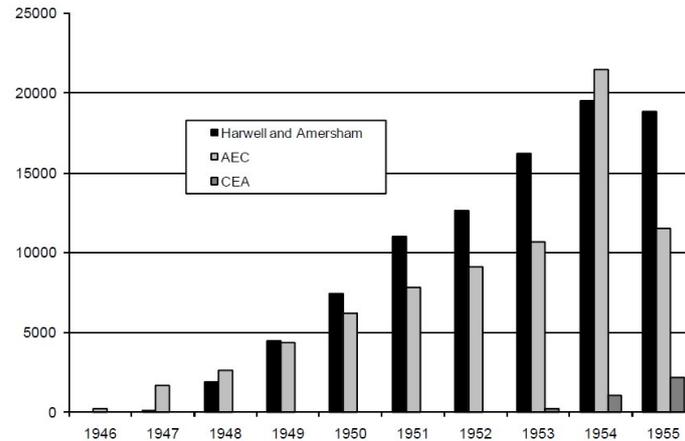


Figure 6: Isotope shipments between 1946 and 1955 by the UK (Harwell and Amersham), the United States (AEC) and France (CEA).⁵¹

However, these new tools of medical research and practice also called for efficient and effective control mechanisms. Contrary to the development of X-rays or radium, radioisotopes were framed from the very beginning in terms of risk associated with their production, distribution and application. As Gaudillière has argued, the case of France was of no exception. In post-war France, from 1949 onwards, the director of INH had to approve all importations if any medical or biological uses were intended. Moreover, safe handling of radioisotopes was normalised by putting in place training courses. These courses were first established in 1950 at the fort Châtillon, CEA's initial site, and they allowed for regular teaching of the safe handling of isotopes⁵².

More importantly, the CEA received in 1952 the State monopoly for radioisotope production, exportation and importation, and steered a national committee composed of actors of various fields (ranging from agriculture and industry to defence) in order to advise on these questions. With Bugnard controlling the circulation of radioisotopes, a specific kind of moral economy emerged with preference given to biochemists and physiologists, allowing at the same time to exclude amateur practitioners as well as those who did not attend the training courses. Thus, radioisotope production (locally and abroad) and the centralised system of distribution and training (in combination with the fellowships that provided transnational networks) closely

⁵¹ Néstor Herran, "Isotope networks: Training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306.

⁵² In Europe, similar developments may be observed in the UK, where training facilities in form of the Isotope School were set up at Harwell around the same time, see: Nestor Herran, "Spreading nucleonics: the Isotope School at the Atomic Energy Research Establishment, 1951-1967," *British Journal for the History of Science* 39/4 (2006), 569-586; see also: Nestor Herran, "Isotope networks: Training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306.

shaped during this first post-war period the rise of biomedicine in France, which saw its institutional recognition with the first nuclear medicine congress held in 1959.

2.2.3. Between crisis and consolidation, 1960-1970

Until the late 1950s, the biological and medical applications of radioisotopes were a crucial element of the public legitimisation of nuclear energy. Radioisotopes were from the very beginning part and parcel of CEA's multifaceted strategy which made plutonium production a priority whilst nonetheless pursuing autonomy in radioisotope production and application in medicine and industry⁵³. However, as Soraya Boudia has shown, despite radioisotope demand coming from the field of biology and medicine was very high (2/3 of the CEA-produced isotopes went to biologists and doctors), these sectors stayed marginal spheres of activity of the nuclear complex as a whole, especially when compared to the significant efforts devoted to reactors and nuclear power plants⁵⁴.

From the mid-1950s onwards, researchers were aware that the use of radioisotopes in cancer treatment showed relatively little success. Antoine Lacassagne, an internationally renowned specialist in the treatment of cancers, declared for instance in 1956 that "results for the use of nuclear energy in the therapy of cancers are still of little importance."⁵⁵ A pessimistic note of the biology section addressed to Louis Bugnard in 1959 comes to similar conclusions: "Some were carried away by an enthusiasm which is understandable and predicted a brilliant future for almost all applications of nuclear energy. However, technological progress, realised at the price of significant complexification of instrumentation, does not translate into important therapeutic results"⁵⁶.

From the early 1960s, biomedicine's role in justifying and legitimising nuclear energy declined, and the role of radioisotopes as shop window of nuclear projects was gradually replaced by energy production, a trend that was significantly reinforced in the 1970s by the oil crisis. Scarce success in the treatment of cancer could have contributed to this demise, but this development

⁵³ Matthew Adamson, "Cores of production: Reactors and radioisotopes in France," *Dynamis* 29 (2009), 261-284. See in more detail: Matthew Adamson, "Commissariat of the Atom: The Expansion of the French Nuclear Complex, 1945-1960," unpublished Dissertation (Indiana University, 2005).

⁵⁴ Soraya Boudia, "Radioisotopes 'economy of promises': On the limits of biomedicine in public legitimization of nuclear activities," *Dynamis* 29 (2009), 241-259.

⁵⁵ Quoted in Soraya Boudia, "Radioisotopes 'economy of promises': On the limits of biomedicine in public legitimization of nuclear activities," *Dynamis* 29 (2009), 255.

⁵⁶ Nonetheless, the letter concludes on a more optimistic note, pointing at the fact that isotopes allow identifying many physiological and biochemical malfunctions, providing great potential for medical diagnostic in the future. See : Pascal Griset and Jean-François Picard, *L'atome et le vivant* (Cherche midi, 2015), 54 (own translation).

was indeed the result of a larger “crisis” related to the 1950s public controversies on nuclear test fallout. Whilst radioisotopes were becoming less dominant⁵⁷, they had nonetheless established, from the early 1960s onwards, a durable presence in a large variety of sectors (scientific research, industry, agriculture, medicine and biology) as now mass-produced products – and the rise of biomedicine actively shaped this development by creating social acceptability for the atom, most notably by demilitarising its image and creating an aura of neutrality⁵⁸.

2.2.4. CEA’s leadership and institutional reorganisation, 1970-2000

From an institutional point of view, throughout the 1960s and 1970s, CEA remained a major actor in French biological research. CEA’s Biology Service, renamed in 1963 Biology Department, did radioisotope related work at the three research centres in Saclay, Orsay and Cadarache under the direct control of Francis Perrin. After a failed fusion of biological laboratories and the radioprotection section, the Biology Department was attached in 1966 to the physics section, with the *Centre d’études nucléaires* in Saclay regrouping now the *Laboratoire de physiologie physicochimique* (LPPC) and four services: biochemistry, biophysics, the *Service hospitalier Frédéric-Joliot* at Orsay hospital and the radioagronomy service in Cadarache (inaugurated in 1963)⁵⁹. Imaging applications specially profited from this centralised control. Under CEAs leadership, new technologies were invented and others refined in order to measure and visualise signals received from radioisotopes, first in autoradiography and spectrometry, later also in chromatography, electronic microscopy, radio-crystallography, nuclear magnetic resonance and the PET scan. The last technique for example allowed at the beginning of the 1970s new crucial insights into the atomic order of molecules.

From early on, a crucial role of the CEA in France was to build strong ties with industry and to encourage research with solid, concrete applications. This strategy in innovation proved however not always very fruitful. One example of a firm that had great potential was the creation in the 1970s of Oris (*Office des rayonnements ionisants*), the CEA Office of Ionising Rays. Its main mission was to develop and commercialise radioactive tracers, provide products for diagnosis in nuclear medicine and radio-pharmacy, and create tests in radioimmunology.

⁵⁷ Nestor Herran, “Isotope networks: Training, sales and publications, 1946-1965,” *Dynamis* 29 (2009), 285-306.

⁵⁸ Soraya Boudia, “Radioisotopes ‘economy of promises’: On the limits of biomedicine in public legitimization of nuclear activities,” *Dynamis* 29 (2009), 258.

⁵⁹ Pascal Griset and Jean-François Picard, *L’atome et le vivant* (Cherche midi, 2015)

Although it saw a solid and strong development during the eighties, it started to struggle during the late nineties. After failed attempts to integrate Oris into a larger international player on the market, BioMérieux, it had to be split up and sold in two parts. Natixis bought in 1998 Cerba, the medical analysis lab of Oris, whereas in 2000, the German pharma group Schering bought its production capacities⁶⁰.

In 1990, the CEA underwent another fundamental institutional reorganisation and created the *Direction des sciences du vivant* (i.e. Life Sciences Division) in order to regroup its activities in its different fields of biological research, ranging from structural biology and research on proteins and pathological agents, to radiobiology and nuclear toxicology, the last being a major focus since the introduction of an environmental and health focus within the agency. Moreover, close ties were established with universities, fostering the training of students at the DEA and PhD level. For instance, in 1993, 200 students were trained, half of them receiving stipends⁶¹. This opening of CEA came along with the introduction of new institutional ties, or the strengthening of old ones, especially with CNRS, INSERM, INRA, French universities but also military services, an institutional landscape that is still shaping isotope research, innovation and the radioisotope market today.

2.2.5. Recent developments

As we have shown in section 1.3, radioisotope supply was confronted to a serious crisis in the 2000s due to the shutdown of research reactors. The main production facility in France is was the Osiris reactor. It underwent during the early 2000s important maintenance procedures at several occasions –contributing therefore actively to the crisis and it was finally shut down in December despite severe criticism from scientists⁶². As a response, France launched in 2007 the construction of a new research reactor (Jules Horowitz Reactor) at the CEA centre in Cadarache, to be delivered in 2013. However, postponed to 2016 and now to 2021, the project has more than doubled in cost. Once in service, the research reactor in Cadarache could cover at least 25% of European demand in terms of ⁹⁹Mo production⁶³.

⁶⁰ Pascal Griset and Jean-François Picard, *L'atome et le vivant* (Cherche midi, 2015), 162-163.

⁶¹ *Ibid.*, 156.

⁶² Pierre Le Hir, "La France va fermer le réacteur Osiris utilisé en médecine nucléaire," *Le Monde*, 14.07.2014.

⁶³ See: <http://www.cad.cea.fr/rjh/fr/radioisotope.html> (accessed on 28/2/2017).

2.3. Germany: isotopes in shifting political landscapes

The German context of the Cold War differs to the other countries studied in this report, as the development of nuclear programmes took place in the context of nation divided in two countries by the so-called “Iron Curtain”. The different socio-political systems in the Federal and Democratic German republics created specific conditions for the development of the radioisotope industry, and provide with an interesting comparative case study about the configuration of the radioisotope market and its relation with the creation of imaginaries about nuclear technology in public opinion.

2.3.1. Research projects in Germany prior to the Cold War

Historians Karin Zachmann and Bernd Gausemeier have shown that German isotope research was largely shaped during this early phase by physicists, biologists and chemists working at different Kaiser Wilhelm Institutes (KWI, the precursors of today's Max Planck Institutes, MPI) and that these actors established well before the Second World War numerous collaborations with industry and scientific institutions⁶⁴. German geneticists such as Hans Stubbe pioneered the new research field of “nuclear agriculture”, by conducting experiments in radiation-induced mutations in plant breeding to improve crop yield and develop specific traits in plants. Experimental systems based on radioactive substances were also put in place in the life sciences and in the industrial sector⁶⁵.

Research into nuclear technologies and radioisotopes did not stop abruptly with the rise of Nazi Germany, although many scientists were forced to emigrate mostly to Northern Europe and the United States. Stricter safety and security regulations were introduced in Nazi Germany out of worries for the health and safety of workers, and radioisotope tracer technologies, pioneered by George de Hevesy in Freiburg during the 1920s, were further developed by mostly analytical chemists, financially supported first by the Bunsen Society, later the Auer Society and located mostly at Kaiser Wilhelm Institutes. Radioisotope research continued during the war and German scientists used seized foreign infrastructures, such as the Paris cyclotron, to produce

⁶⁴ This section follows largely Karin Zachmann analysis and picks up on major conclusions she has drawn in her paper “Peaceful atoms in agriculture and food: how the politics of the Cold War shaped agricultural research using isotopes and radiation in post war divided Germany,” *Dynamis* 35/2 (2015), 307-331. See also: Bernd Gausemeier, *Natürliche Ordnungen und politische Allianzen: biologische und biochemische Forschung an Kaiser-Wilhelm-Instituten 1933-1945* (Wallstein, 2005).

⁶⁵ Alexander von Schwerin, “Prekäre Stoffe. Radiumökonomie, Risikoepisteme und die Etablierung der Radioindikator-technik in der Zeit des Nationalsozialismus,” *NTM: Zeitschrift für Geschichte der Naturwissenschaften, Technik und Medizin* 17 (2009), 5-33, here 10.

radioisotopes for physicians, chemists, biologists and physicists doing research in France and Germany⁶⁶.

Germany's defeat in the Second World War interrupted these researches, in particular in the GDR. Declared by the Allied forces as "prohibited research", nuclear research related instruments became rare. The Allied Control Council Law No. 25 of 1946 and the Allied High Commission Law No. 22 of 1950 introduced strict research prohibitions, in particular in regard to nuclear technologies⁶⁷. Soviet occupation led indeed to the forced relocation of important scientific researchers in the field (i.e. Nikolaus Riehl, Klaus-Günther Zimmer, Nikolaj Timoféev-Ressovski and Hans-Joachim Born) and a major stalemate of German radioisotope research.

2.3.2. The Cold War and the special case of the GDR

Although Allied prohibitions on nuclear research were enforced in both Germanys, the different political dynamics in West and East Germany led to diverging trajectories. The circulation of radioisotopes was tightly linked up to international politics, especially when countries different from the United States began their own distribution programmes⁶⁸. In West Germany research restrictions were not as strict as envisaged by the Allied Control Council Law, and legal provisions were introduced to allow radioisotope research in some places from the late 1940s. Hence, West German scientists gained access to material and intellectual resources on radioisotopes far more quickly than their colleagues in the German Democratic Republic, where such provisions were not made and radioisotope research was banned until the mid-1950s⁶⁹.

Thus, radioisotope research did not pick up in East Germany until 1955 and, when it did, it relied heavily on Soviet cooperation and assistance. Moreover, during the first half of the 1950s, the East European bloc was denied access to radioisotope shipments from the West. East German scientists were also impeded to attend training courses, in the UK for instance, until the

⁶⁶ Ibid.

⁶⁷ Karin Zachmann, "Peaceful atoms in agriculture and food: how the politics of the Cold War shaped agricultural research using isotopes and radiation in post war divided Germany," *Dynamis* 35/2 (2015), 311.

⁶⁸ Numerous historians studied the political function of radioisotopes. See for instance: John Krige, "The Politics of Phosphorus-32: A Cold War Fable based on Fact," *Historical Studies in the Physical Sciences* 36 (2005), 71-91; Néstor Herran, "Isotope networks: training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306; Angela Creager, "Radioisotopes as political instruments, 1946-1953," *Dynamis* 29 (2009), 219-239.

⁶⁹ This is a major claim of Karin Zachmann. The paragraph is mostly based on her article "Peaceful atoms in agriculture and food: how the politics of the Cold War shaped agricultural research using isotopes and radiation in post war divided Germany," *Dynamis*, 35/2 (2015), 307-331 as well as on Néstor Herran, "Isotope networks: training, sales and publications, 1946-1965," *Dynamis* 29 (2009), 285-306.

end of the 1950s and they thus had to turn to the Soviet Union to ask for help⁷⁰. This request was officially granted only in 1955 when the Soviet Union agreed to allow German scientists to return to the GDR and to provide a research reactor and a cyclotron for research purposes⁷¹. Radioisotopes were identified as one of the most promising peaceful uses of the atom, especially for economic reasons. An early position paper from 1950 already outlined that radioisotope research and energy production would eventually guide the GDR nuclear programme⁷². Radioisotope production and applications in “chemistry, metallurgy, medicine, and the agricultural sciences” were praised, with the authors insisting in particular on the high price of these materials on the international market. The national production of radioisotopes would provide autonomy and promised to bring about new economic opportunities⁷³.

Universities were amongst the first isotope users. At Friedrich Schiller University in Jena, plant physiologist Gerhard Michael conducted tracer studies since 1955 with radioactive phosphorus imported from Moscow, and a first particle accelerator was also installed in 1956. And as in the case of West Germany, radioisotope distribution was organised through a former Kaiser Wilhelm Institute in East Berlin (Berlin-Buch which became a major centre for nuclear medicine). The agency imported radioisotopes from the Soviet Union or received shipments from Rossendorf (near Dresden), where a research reactor was installed in 1957 with the help of the Soviet Union. The official distribution agency worked from 1958 onwards for almost half a decade and organised allocations for all the research institutes and universities in the GDR. A Commission for Isotope Research was also set up with the main goal of coordinating research in the GDR and formulating research priorities. The SED party put a lot of pressure to produce concrete results on GDR scientists, who in return tried to attenuate the often unrealistic expectations.

After the Second Atoms for Peace Conference in 1958, applied aspects became even more dominant, with radioisotope research as an important shop window for technological progress and therefore of soft power –a similar development to what may be observed on the other side

⁷⁰ Harald Deckart, Bernd Schicke and Katja Thiele, *Geschichte der Nuklearmedizin in Ostdeutschland, Summary Report* (no place and date), 1-56. See also: Néstor Herran, “Spreading Nucleonics: the Isotope School at the Atomic Energy Research Establishment, 1951-1967,” *British Journal of the History of Science* 39/4 (2006), 569-586.

⁷¹ For the history of the nuclear industry in the GDR, see also: Thomas Stange, *Institut X: Die Anfänge der Kern- und Hochenergiephysik in der DDR* (Teubner, 2001); Mike Reichert, *Kernenergiewirtschaft in der DDR* (Scripta Mercatorae Verlag, 1999).

⁷² *Vorschläge über Arbeiten auf dem Gebiet der Kernphysik in der Deutschen Demokratischen Republik*, 09.02.1950, cited in: Olaf Strauß, *Die Kernforschung und Kerntechnologieentwicklung in der DDR 1945-1965*, unpublished PhD manuscript (Greifswald University, 2011), 84.

⁷³ *Ibid.*, 97.

of the Iron Curtain. The nuclear sector formed from this early period onwards an important part of GDR's national identity, inscribed in many political resolutions and representing the superiority of socialism over capitalism⁷⁴. Moreover, national publicity campaigns launched in 1955 tried to reduce public fear of the "spectre of the atom" and to enthuse the public for its peaceful uses⁷⁵.

Establishing radioisotope research required an intensification of research contacts throughout the East bloc. GDR scientists were relatively isolated behind the Iron Curtain, even though they had at least partially access to the literature of the West. Their research network was institutionalised in 1960 with the Standing Commission for Peaceful Uses of the Atom. In comparison, West Germany remained clearly ahead during this early period, also due to its rather rapid integration into transnational collaboration networks, in particular through the support of the United States.

The construction of the Berlin wall in 1961 increased the isolation of GDR scientists, as they couldn't attend international conferences nor visit international institutions⁷⁶. Indeed, they only could publish with special permission in international journals and were forced to set up their own journals. The divide was bridged occasionally by the transnational scientific community, allowing the participation of foreign scientists in their editorial boards, or the invitation of influential figures of GDR nuclear medicine (such as Harald Deckart and Wilhelm Finck) to become editorial board members of foreign international journals.

Funding was very limited, with relatively few resources available to buy instruments or radioisotopes on the international market, which was in many cases restricted to the Eastern bloc. As a consequence, a culture of autodidactic learning was instigated in combination with a new emphasis on innovation and in particular the construction of self-designed instruments as well as the production of radiolabelled drugs. Moreover, in order to assure self-sufficiency in the medical sector, each clinic disposed of its own electronic laboratory that was in charge of the radio-medical instruments.

⁷⁴ Johannes Abele, *Kernkraft in der DDR: Zwischen nationaler Industriepolitik und sozialistischer Zusammenarbeit 1963-1990* (TU Dresden, 2000), 11.

⁷⁵ Olaf Strauß, *Die Kernforschung und Kerntechnologieentwicklung in der DDR 1945-1965*, unpublished PhD manuscript (Greifswald University, 2011), 216f..

⁷⁶ Michael Feld and Michel De Roo, *History of Nuclear Medicine in Europe* (Schattauer, 2003), 49-50.

Medical staff participated in the elaboration of 5-year plans, coordinating the systemic establishment of nuclear medical centres on the entire territory: 10 centres were put in place between 1955 and 1964, 5 more between 1965 and 1974, and finally 17 additional centres were established between 1975 and 1989. The larger medical centres, located exclusively at university hospitals (allowing for both, clinical diagnostics *and* therapy), received the bulk part of the funding, accompanied by smaller investments into regional hospitals in order to establish clinical diagnostics capabilities. Scientists, engineers, nuclear chemists, clinical physicists and other staff were employed at each centre to assure the functioning of the instrumentation and to develop new ones, as well as to synthesise and label drugs.

From 1967 onwards, the GDR published annual reports on nuclear medicine, synthesising all activities of its nuclear medical centres. These reports show a gradual increase of in-vitro diagnostics between 1957 and 1986, replacing from the mid-1970s onwards almost entirely any other forms of clinical diagnostics. Amongst the most used radioisotopes count first (to a smaller degree) gold-198 and phosphorus-32, and for the vast majority iodine-131, used in around 200 therapies in 1950 and rising steadily to over 2000 therapies in 1988.

During the 1970s, the active opening at a scientific level to European integration became an essential strategy of GDR politics. Important figures of the GDR nuclear medical sector participated in the elaboration and founding of the first European Nuclear Medicine Society (ENMS, founded in 1972), which merged in the mid-1980s with the Society of Nuclear Medicine Europe (founded in 1962) to become the European Association of Nuclear Medicine.

Particular mention has to be made of “Isocommerz” that was first established in the 1950s as a radioisotope distribution organisation and that received in 1969 the monopoly for commercialising all stable isotopes and all radioisotope tracer material⁷⁷. Its director, Walter Merz, pushed the nuclear medical sector in unconventional ways, a legacy that was later picked up by his successor Günter Ewald. Most importantly, Merz initiated at the beginning of the 1970s the Cooperative Union for Isotope and Nuclear Technics (Kooperationsverband Isotopen- und Strahlentechnik) based in Leipzig that had a role similar to national atomic energy agencies nowadays. Substantial funding was provided and it was chaired by 15 scientists that developed ambitious five-year-plans together with representatives from agriculture, the armed forces, industry, mining and medicine. The medical sector benefited especially from the funding

⁷⁷ Michael Feld and Michel De Roo, *History of Nuclear Medicine in Europe* (Schattauer, 2003), 50.

provided for research projects that were coordinated by a special committee. Isocommerz had also an international economic function. For instance, some scientists that participated in the medical research projects promoted during their travels abroad the export of GDR produced radiolabelled drugs. Finally, several journals edited by Isocommerz allowed to publish the research results, to validate the scientific research undertaken and, in a more general way, to portray these activities as a fruitful application of the peaceful uses of the atom⁷⁸.

Despite major efforts in promoting the benefits of the atom, social protest movements started to form from the late 1970s onwards, pointing at many environmental problems brought about by the socialist state. It was not clear from the very beginning that this movement would eventually lead to a critic of the entire political system, since environmental protection was also at least in part an important concern (even though underdeveloped) of GDR party leadership. In order to channel the new social movements and to respond to these growing environmental concerns, the state party founded in 1980 the "Society for Nature and Environment (Gesellschaft für Natur und Umwelt)". However, independent environmentalist groups insisted on breaching this information monopoly of the state, calling in particular for more active social participation in party decisions. GDR political leadership did obviously not approve these social demands and the environmental movement was thus pushed inevitably into the role of direct State opposition.

As in the West, 1970s criticism focused on the dysfunctions of the technocratic order and, more specifically, on the naïve belief in progress promoted by the socialist state. Activists and members of the protestant church used similar arguments and, although some exchange of ideas with party representatives was at the beginning still possible, this changed during the early 1980s when the State reclaimed the information monopoly regarding environmental information. This imminently political dimension of the nuclear question became in the wake of Chernobyl a major concern for large parts of society, fuelled by a growing frustration over lack of information and leading eventually to the regime's demise⁷⁹. The FRG took over control of the nuclear sector in 1990 and decided, in view of the severe security deficiencies in case of most reactors, to shut down all reactors, including the research reactor in Rossendorf, bringing the former GDR nuclear sector to a definite end.

⁷⁸ See: Harald Deckart, Bernd Schicke and Katja Thiele, *Geschichte der Nuklearmedizin in Ostdeutschland, Summary Report* (no place and date), 27.

⁷⁹ Johannes Abele, *Kernkraft in der DDR: Zwischen nationaler Industriepolitik und sozialistischer Zusammenarbeit 1963-1990* (TU Dresden, 2000), 90-104.

2.3.3. Parallel developments in Western Germany

In West Germany, radioisotope research set out in Göttingen, which quickly became a major hub for short half-life radioisotope distribution. In 1949, the British authorities allowed the local Max Planck Institute for Medical Research, established in 1947, to distribute radioisotopes produced in Harwell in West Germany⁸⁰.

These early shipments were complemented by the training courses that the British AERE put in place in 1951 in Harwell's Isotope School, in which West German participants were the largest group of graduates between 1951 and 1956⁸¹. At the beginning of the 1950s, most of the radioisotopes were used in the different Max Planck Institutes. For instance, Frankfurt saw the establishment of a Department of Radioactive Isotopes at the Max Planck Institute for Biophysics, and the Tübingen had the Biochemistry Max Planck Institute continue research on the tobacco virus with the help of radioactive tracers. Universities participated into radioisotope research rather early, with the University of Bonn conducting animal physiology experiments and the Justus Liebig University in Giessen researching fertilizer processes. At the Bavarian Weihenstephan Agricultural Chemistry Institute, researchers were interested in similar questions, which they intended to study first with the help of phosphorus-32, and later by using radioactive nutrients in crop studies⁸². There was also some interest in radioisotope research at the federal level, with several federal institutes involved in research projects ranging from food preservation through irradiation (in Karlsruhe) and metabolism studies of grape plants (in Siebeldingen), to growth studies conducted at the Federal Research Centre for Forestry and Wood Products using carbon-14 and strontium-90 to investigate the growth of trees⁸³.

⁸⁰ Karin Zachmann, "Peaceful atoms in agriculture and food: how the politics of the Cold War shaped agricultural research using isotopes and radiation in post war divided Germany," *Dynamis* 35/2 (2015), 307-331, here 312-313.

⁸¹ See figure 3 in: Néstor Herran, "Spreading Nucleonics: the Isotope School at the Atomic Energy Research Establishment, 1951-1967," *British Journal of the History of Science* 39/4 (2006), 569-586, here 582.

⁸² Karin Zachmann, "Peaceful atoms in agriculture and food: how the politics of the Cold War shaped agricultural research using isotopes and radiation in post war divided Germany," *Dynamis* 35/2 (2015), 307-331, here 314; Zachmann uses here and in the following examples mostly archival material from the German Bundesarchiv.

⁸³ *Ibid.*, 314.



Figure 7: Uses of radioisotopes at the Institute of Botany and Microbiology in Juelich, Germany
(Source: IAEA archives, ref. 011c)

As Karin Zachmann has shown, most of these research projects required rapid acquisition and transportation of radioisotopes which was in part funded by the German Research Council (Deutsche Forschungsgesellschaft, DFG) and the European Recovery Program. In this early phase of West German research, even funding provided by the Marshall Plan went into projects that normally would have been prohibited, but special legal provisions allowed for. This means that in the case of West Germany, research on radioisotopes picked up quickly after the War thanks to liberal allied politics. Indeed, well before being granted full national sovereignty and even before the full opening of the nuclear research sector, numerous research activities could be carried out in the nuclear field. More specifically, this allowed either to continue research activities (most notably in biology and the life sciences) that were at least in part already underway during the 1930s and early 1940s at different Kaiser Wilhelm Institutes, or to engage entirely anew (such as in the field of food irradiation) in what was considered at the time a highly prestigious research field.

This situation changed radically during the mid-1950s, when both the Federal Republic of Germany and the German Democratic Republic installed nuclear research reactors⁸⁴. Just as in the GDR, the Federal Republic of Germany entered in 1955 a new historical phase in the field of nuclear research. The newly gained national sovereignty allowed most notably for the creation of the Ministry of Atomic Affairs, headed by Franz Josef Strauss. An Atomic Advisory Board, the equivalent of the GDR's Commission of Isotope Research, was set up in November 1955 in order to achieve a faster transition to the atomic age, adequate safety measures and a monitoring programme of radioactivity. Despite the highly optimistic expectations, environmental and health concerns surfaced in public debate due in part to the fallout controversy in 1954. Hence, the Commission considered "military" and "peaceful" applications, whereas military measures mostly referred to measures to be taken after a nuclear attack⁸⁵. Food irradiation became during the latter half of the 1950s an important research field, with substantial funding going to federal institutes.

The analysis of the most important German daily newspaper largely confirms the ambivalent public image of nuclear activities during the 1950s⁸⁶. On the one hand, the medical sector benefited from a strong positive image despite the absence of concrete applications. Journalists frequently praised the great potential of tracers in nuclear medicine and the strong hopes for cancer research⁸⁷. On the other hand, these great hopes were accompanied by far more critical voices, emanating mostly from the United States after publicly contested atmospheric nuclear tests. The new research potential emerging within the Earth sciences (for observing for instance global processes in oceanography and the atmospheric sciences) was thus accompanied by fears of possible radioactive contamination (through for example rain exposure or consumption of milk products)⁸⁸.

These developments were shaped in West Germany by broader political commitments to scientific research⁸⁹. In 1957, Theodor Heuss proposed for the Federal Republic of Germany the formation of a new commission in order to promote science: the German Science

⁸⁴ Ibid., 315.

⁸⁵ Ibid., 328.

⁸⁶ We systematically analysed the entire archive of the *Frankfurter Allgemeine Zeitung* covering 1950-2013.

⁸⁷ "Atomphysik hilft heilen," *FAZ*, 18.01.1951; "Die Krebserreger – Befürchtungen und Hoffnungen," *FAZ*, 17.10.1951; "Der Kampf gegen den Krebs," *FAZ*, 18.09.1953; "Noch keine chemischen Krebsheilmittel," *FAZ*, 27.12.1958..

⁸⁸ "Radioaktive Strahlen – die Gefahren unserer Zeit," *FAZ*, 08.05.1957; "Amerikanischer Wissenschaftler warnt vor Radioaktivität," *FAZ*, 09.05.1957. See also: Nestor Herran, "'Unscare' and Conceal: The United Nations Scientific Committee on the Effects of Atomic Radiation and the Origin of International Radiation Monitoring," in Simone Turchetti and Peder Roberts (eds.), *The Surveillance Imperative* (Palgrave, 2014), 69-84, here 73.

⁸⁹ For this section see: Karl Winnacker and Karl Wirtz, *Atome: illusion ou miracle?* (PUF, 1977), 177-196.

Commission (*Deutscher Wissenschaftsrat*). Its main objective was to promote science, to identify research priorities, and to define political and economic responsibilities at the regional and federal level. With substantial increases in funding coordinated at both levels (federal and regional), radioisotope research was now being carried out at various places: in University and College institutes, at federal institutes but also many Max Planck Institutes. The research fields were also more and more diversified. In particular, industrial applications of radioisotopes became an important field of research and development. The “Gemeinnützige Isotopengesellschaft” founded in 1957 and introduced with the expertise of nuclear researchers in Karlsruhe, promoted explicitly industrial applications of radioisotopes⁹⁰.

Karlsruhe became hence, during the second half of the 1950s, an important industrial research centre in this domain, developing applications such as the study of the wear of motors with the help of radioisotopes. The radiochemical laboratory of Hoechst, under the direction of Hans Götte -who also presided at the time the “Working Group on the protection against radiation in the manipulation of radioactive substances”- engaged for its part in environmental research, most notably marine current and sedimentation studies. The use of radioisotopes in medical research was in large parts the fruit of Hugo Wilhelm Knipping, former director of the University hospital in Cologne. He promoted the medical uses of radioisotopes and pushed for the creation of a research institute dedicated to these matters at the nuclear centre in Jülich. The medical congress dedicated to “nuclear radiation in medicine and technology” that was held in Munich during the German Atomforum in 1963 was the fruit of his initiatives.

After this initial phase of marked ideological contrast between the Eastern and Western parts of Germany, a period of détente gradually found its way into politics, opening dialogue and slowly enabling scientific cooperation also across the Iron Curtain. In particular the field of nuclear medicine saw from 1965 onwards almost exponential growth⁹¹. This development went hand in hand with important technological innovations especially in the medical imaging sector. However, by exposing patients to a growing variety of radioactive substances, stricter protective measures were also called for, turning by the mid-1970s also the medical sector into a controversial issue⁹².

⁹⁰ FAZ, 17.04.1957.

⁹¹ “Nuklearmedizin in rascher Entwicklung,” FAZ, 13.09.1967.

⁹² “Zu hohe diagnostische Strahlenbelastung,” FAZ, 28.12.1972; “Die Strahlenbelastung in der Bundesrepublik,” FAZ, 15.05.1974; “Kontroverse um Strahlenrisiko,” FAZ, 24.04.1975.

According to frequent newspaper reports, by the early 1970s, the different networks of water and air quality surveillance were providing mostly reassuring results. Indeed, since the Nuclear Test Ban Treaty (NTBT) introduced in 1963, atmospheric carbon-14 (radiocarbon) concentrations were declining and the general presence of radioactive isotopes in the air diminished significantly⁹³ – even though all major detonations remained clearly detectable⁹⁴. Yet this did certainly not mean that the nuclear sector benefited from a new form of social acceptance. The rise of the ecological movement had in West Germany strong roots in the anti-nuclear movement and was politically institutionalised in 1980 in form of the Green party (*Die Grünen*). They entered the Bundestag in 1983 and helped organise much of the nuclear critic and resistance in Germany especially since their fusion after the reunification with parts of the East German peace movement (when they became *Bündnis90/Die Grünen*). Moreover, the rise of the Green party in Germany may at least in part be understood as a reaction to major nuclear accidents. In particular the second half of the 1980s was strongly influenced by the 1986 Chernobyl disaster, with different social movements calling now for far stricter protective measures, especially for children⁹⁵.

2.3.4. Radioisotopes in Germany after the reunification

Most Environmental questions had a strong impact not only on how radioisotopes were perceived but also how they were used. Indeed, after the Cold War, our press analysis reveals a rapidly growing spectrum of environmental applications of radioisotopes and of isotopic analysis in general, most of which had already been developed during the Cold War but now saw a large diversification due to topics with growing political and scientific importance, most importantly climate change. These include in particular tracer applications in biochemistry and the analysis of isotopic composition in ice cores or corals, revealing the climatic conditions of the past. Moreover, tracers could now also help detect environmental crimes, in particular illegal trading but also illegal pollution⁹⁶. The Earth sciences thus saw in general a broad diversification of application fields, a development that is in line with broader historical developments in the sciences and a general rise of environmental questions in the public sphere.

⁹³ "Radioaktive Spaltprodukte im Regen," *FAZ*, 21.05.1966 ; "Kaum Radioaktivität in der Nordsee," *FAZ*, 13.09.1972; "Geringe Radioaktivität," *FAZ*, 24.01.1973.

⁹⁴ "Neutronendosis in Hiroshima nachträglich feststellbar," *FAZ*, 06.04.1983.

⁹⁵ "Eltern und Erzieher fordern Vorsorgemaßnahmen," *FAZ*, 09.05.1986.

⁹⁶ "Die Kohlenstoff-Uhr tickt nicht richtig," *FAZ*, 13.06.1990; "Elfenbein gibt seine Herkunft preis," *FAZ*, 12.09.1990; "Dem antiken Handel auf der Spur," *FAZ*, 02.05.1991; "Auf Spurensuche in der Antarktis," *FAZ*, 20.05.1992; "Chemischer Fingerabdruck verrät Umweltsünder," *FAZ*, 02.03.1994; "Biochemiker erforschen Struktur und Funktion von Proteinen," *FAZ*, 03.05.1996.

More surprisingly, whereas the uses of radioisotopes within the medical sector were considered revolutionary during the 1950s and 1960s – newspaper reports frequently praised the great medical potential –, their uses seem normalised by the 1990s, with relatively few press articles addressing medical issues. From 2000 onwards, medical radioisotopes are mentioned almost exclusively in the context of an impending European supply crisis (especially of technetium-99), a crisis for which the major radioisotope producers are still trying to find a durable solution (see also the general discussion in this report)⁹⁷.

Finally, the Japanese Fukushima catastrophe in March 2011 had a lasting impact in several ways. As described in detail in the German national report, Gerhard Schröder introduced a slow phasing out of nuclear energy in 2000 known as “atomic consensus (*Atomkonsens*)”, a consensus that was at first rejected by Merkel in 2010 and transformed into new temporal extensions for most German reactors. However, the Fukushima catastrophe led to a radical political rethinking, accompanied by the resurfacing of large anti-nuclear movements with important demonstrations in major German cities. German nuclear energy was thus declared coming definitely to an end – even in the case of new political constellations in the future. The press frequently picked up on Fukushima in relation to radioisotopes, revealing important environmental consequences, fuelling the anxieties that contributed to the fundamental reorientation of the entire German nuclear sector⁹⁸.

⁹⁷ “Nuklearmedizin in Not,” *FAZ*, 04.02.2009.

⁹⁸ “Kabeljau mit ein wenig Becquerel,” *FAZ*, 25.03.2011; “Von Jod bis Plutonium: Das “Auswurfmaterial” aus den Fukushima-Reaktoren ist noch überschaubar,” *FAZ*, 01.04.2011; “Das elementare Böse,” *FAZ*, 03.04.2011; “Tokio: Der Kampf in Fukushima zieht sich in die Länge,” *FAZ*, 04.04.2011; “Zweierlei Halbwertszeiten,” *FAZ*, 05.04.2011; “Jungfische vor Fukushima mit Cäsium belastet,” *FAZ*, 06.04.2011.

2.4. Spain: radioisotopes and ‘nuclear modernisation’

Spain has not been traditionally a major player of the radioisotope market, but the history of its relation to radioisotopes has two distinctive features justifying its study. First, Spain was under a military dictatorship for most of the Cold War period. This political context was characterised by autarchic economic policies, a strict control of the media and repression of political dissent. This crucially shaped the ways the nuclear programme was established and articulated with other economic sectors as well as its representation before Spanish society. Second, the support of the nuclear project by the Spanish government was very important in relation to the weak economic weight of the country, leading to effects and tensions with other scientific areas and shaping Spanish techno-scientific policy⁹⁹.

2.4.1. Radioactivity in Spain before the Second World War

Despite the existence of a radioactivity laboratory since 1904 and a full institute since 1911, Spain cannot count amongst the most advanced countries in the field of radioactivity in the early 20th century. The lack of a national radium industry, and the difficulties in keeping in tune with more advanced theoretical developments (the focus being on the legitimisation of spa cures and the application of radioactivity to agriculture) led to a disconnection with mainstream developments in this area. However, some research efforts in the localisation of radioactive sources led to a first cartography of uranium deposits in Spain, and the building of some expertise in the measurement of ionizing radiation, including the development of instruments¹⁰⁰.

In the 1930s, as part of a wider effort for building scientific infrastructure and expertise through training in foreign research laboratories, some arrangements to keep up with recent tracer technique developments were made, with at least one student (Piedad de la Cierva) travelling to Copenhagen to work under the direction of George Hevesy. However, the Spanish Civil War cut with this career path, and de la Cierva redirected her further efforts to the production of optical instruments for the military¹⁰¹.

⁹⁹ On nuclear energy and modernization, see: Ana Romero de Pablos, and José Manuel Sánchez Ron, *Energía Nuclear en España. De la JEN al CIEMAT*. (Madrid: Doce Calles, 2001); Albert Presas, “Science on the Periphery. The Spanish Reception of Nuclear Energy: An Attempt at Modernity?” *Minerva* 43/2 (2005), 197–218. For an inside history of the Spanish nuclear program, see: Rafael Caro, *Historia Nuclear de España* (Sociedad Nuclear Española, 1995).

¹⁰⁰ Néstor Herran, *Aguas, semillas y radiaciones. El laboratorio de radioactividad de la Universidad de Madrid, 1904-1929* (Madrid: CSIC, 2008).

¹⁰¹ Nestor Herran, Interview with Piedad de la Cierva (8 november 2004).

After the Civil War, research stagnated until 1945, when interest for the military uses of atomic energy led to the establishment of a secret nuclear project led by the military and to the revitalisation of the remains of the institute of radioactivity under the supervision of the National Institute of Geophysics (*Instituto Nacional de Geofísica*, ING). Although most ING activities were directed to the exploration of uranium deposits, the institute organised the earliest training programmes on isotope techniques¹⁰².

At the same time, medical uses of radioisotopes attracted the attention of Spanish oncologists or endocrinologists interested in the use of iodine-131 in the treatment of thyroid diseases (hyperthyroidism being still endemic in some regions of Spain). Thus, by 1948 a first research unit was created in the Red Cross hospital in Madrid under the direction of Carlos Blanco Soler who had previously participated in the establishment of the Spanish Society of Medical Radiology and 'Electrology'. These groups, which in some cases organised some training courses at a local level, did not rely on much official support, and were ignored by the media¹⁰³.

2.4.2. Radioisotopes and the Spanish nuclear program

In 1951, the Spanish Nuclear Energy Board (*Junta de Energía Nuclear*, JEN) was established in order to organise all research and development in relation to nuclear matters in Spain. The decree instituting the JEN also granted the board the control over the "acquisition, distribution and use of radioactive isotopes" and the "specialised training of scientists and technicians on all subjects related to nuclear energy"¹⁰⁴. This state monopoly on the import of radioisotopes was however purely formal, there were virtually no Spanish experts in the field and the lack of nuclear reactors made Spain totally dependent of foreign imports. Thus, centres of nuclear medicine continued to proliferate and established specific radioisotope supply agreements, which were also limited by financial constraints and difficulties in obtaining foreign currency¹⁰⁵.

¹⁰² Néstor Herran, *Aguas, semillas y radiaciones. El laboratorio de radioactividad de la Universidad de Madrid, 1904-1929* (Madrid: CSIC, 2008), 199-205.

¹⁰³ The history of these groups has been studied quite extensively by Maria Jesus Santesmases: Maria Jesus Santesmases, "From Prophylaxis to Atomic Cocktail: Circulation of Radioiodine", *Dynamis* 29 (2009), 337-63; Maria Jesús Santesmases, "Peace Propaganda and Biomedical Experimentation: Influential Uses of Radioisotopes in Endocrinology and Molecular Genetics in Spain", *Journal of the History of Biology* 39 (2006), 765-94.

¹⁰⁴ *Decreto Ley de la Presidencia del Gobierno*, 22 October 1951.

¹⁰⁵ Manuel Castell, *Historia de La Medicina Nuclear En España. Sus Primeros Cuarenta Años* (Cetir, 1993)

The Atoms for Peace initiative, as well as changing economic policies leading to the abandon of autarky, provided an important push to the institutionalisation of radioisotope distribution and research. In 1955, an Advisory Committee on Health and on the Promotion of the Application of Radioisotopes (*Comisión Nacional de Sanidad sobre las Aplicaciones de la Energía Atómica*) was established to oversee the import, distribution and uses of radioisotopes in Spain. A leading actor of this committee was Miguel Ángel Gamboa-Loyarte, a chemist by training that had attended Harwell's isotope school in 1952. Gamboa-Loyarte was one of the seventeen members of the Spanish delegation at the 1955 Atoms for Peace conference in Geneva and in the following years he participated in practically all committees and commissions related to the use of radioisotopes in Spain. His early efforts were directed to constitute a community of experts on the use of radioisotope techniques, by sending Spanish scientists and engineers to foreign courses in the United States, the United Kingdom and France.

The building of a group of experts in radioisotope-related techniques benefited from the important public exposure of the so-called "peaceful applications of nuclear energy". Since the Geneva conference, the Spanish press covered in detail the uses of isotopes in agriculture, medicine and industry. This was accompanied by the exhibit of itinerant US AEC public displays, such as "The Atom in industry and agriculture" in Spanish cities, as well as the screening of AEC produced documentary in the Spanish official newsreel, NO-DO. The second conference in Geneva (1958), at which radioisotope-related applications of nuclear energy were quite prominent, was also extensively covered by the Spanish Press¹⁰⁶. This attention probably contributed to the establishment in 1956 of the JEN Isotopes Division, directed by Gamboa-Loyarte and his collaborator Manuel del Val Cob. The Division was in charge of the acquisition and supply of radioisotopes, the "information to users and public", the control and supervision of radioisotope use and the promotion of the applications of radioisotopes. This policing was implemented by the establishment of a "user of isotopes" diploma, which was awarded in connection to several training activities promoted by the JEN¹⁰⁷.

The Isotopes Division was initially located at the Institute of Oncology Research at the Clinic Hospital in Madrid, a choice that reflected the pioneering role of medical researchers in the field. However, the growth of the JEN led to the transfer of the team to the JEN facilities at the Juan

¹⁰⁶ Alfredo Manéndez, "Átomos para la Paz... y para la Medicina: la popularización de las aplicaciones médicas de la energía nuclear en España", *Revista Española de Medicina Nuclear* 26/6 (2007), 385-99.

¹⁰⁷ Manuel Castell, *Historia de La Medicina Nuclear En España. Sus Primeros Cuarenta Años* (Cetir, 1993)

Vigon's National Centre of Nuclear Energy (*Centro Nacional de Energía Nuclear Juan Vigón*) in Madrid in 1959. There, work began on the first Spanish nuclear research reactor (JEN-1), which had been conceived as a neutron source for isotope production and chemical analysis by activation. Indeed, it was used as a source of gamma rays for materials research, food irradiation and sterilisation of medical utensils. All these activities were fuelled by international contacts, principally with US researchers from Oak Ridge, as the installation of the reactor was part of a broader agreement on nuclear matters between Spain and the United States, which included an article devoted to the exchange of radioisotopes and scientific equipment¹⁰⁸.

2.4.3. The promotion of industrial uses of radioisotopes in the 1960s

Whereas during the 1950s the JEN oversaw the early institutionalisation of radioisotope research, in the 1960s it led an ambitious programme to promote the industrial uses of isotopes. The division of isotopes, which counted in 1960 ten researchers, contributed to the establishment of courses on nuclear engineering in Spanish universities, produced the first industrial gamma ray radiographies using cobalt-60, iridium-192 and cesium-137, and established ties with medical profession by participating in a commission of radiological protection.

At the same time, the isotope division began to set the bases of a national radioisotope supply chain. Distribution was made by the private company Técnicas Nucleares SA, established in 1957 and charged initially of the distribution of imported radioisotopes.¹⁰⁹ In 1961, a small amount of phosphorus-32 was produced in the JEN-1 and distributed to a Spanish hospital. Rising production at the JEN-1 fostered local supply, and by 1967, as much as 80% of all national demand was covered by JEN reactors. However, this process of "nationalisation" began to recede some soon after the passing of a law authorising private companies, either foreign (such as Amersham) or national (such as General Radioquímica or Nuclear Ibérica), to sell radioisotopes and tagged molecules¹¹⁰.

¹⁰⁸ Ana Romero de Pablos, and José Manuel Sánchez Ron, *Energía Nuclear en España. De la JEN al CIEMAT*, (Doce Calles, 2001), 91-156.

¹⁰⁹ Luis Sánchez-Vazquez, *La legitimación de la energía nuclear en España: El Forum Atómico Español (1962-1979)*, Universidad de Granada, 2010.

¹¹⁰ *Ley 25/64 de liberalización del Mercado de isótopos*.

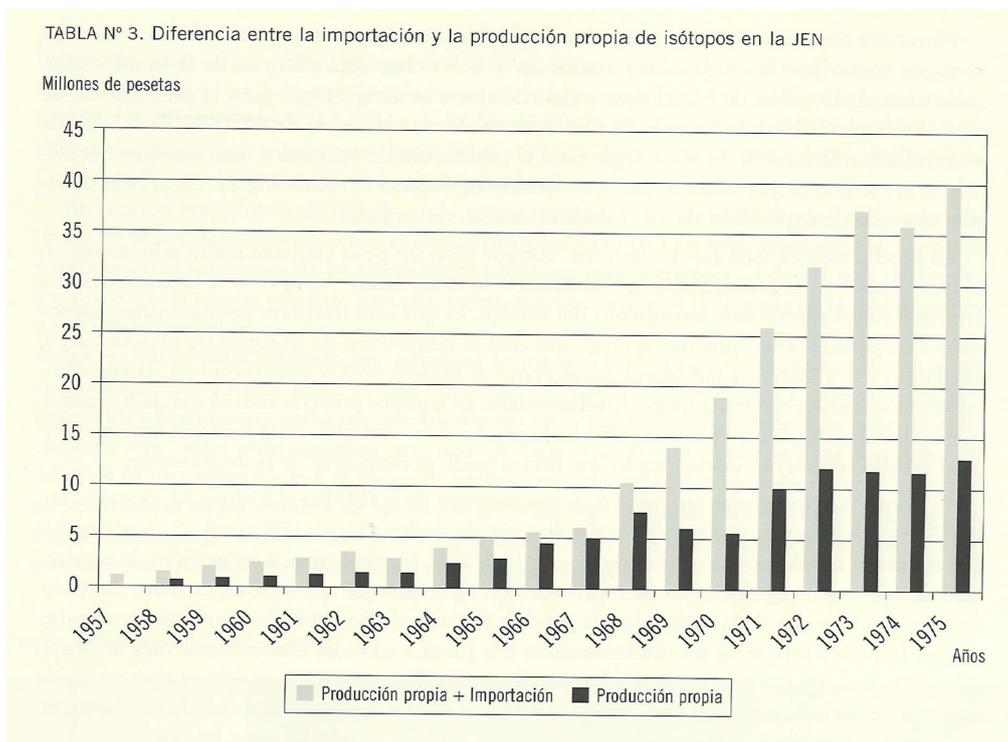


Figure 8: Imports and nationally produced radioisotopes in Spain, 1957-1975¹¹¹.

The Isotope Division at the JEN was also active in fields such as food irradiation. A big irradiation unit, called Náyade, was built in 1964 and used for materials research, chemical research, polymerisation, dosimetry production, and food preservation. Náyade was thus the main equipment allowing Spanish researchers to participate in IAEA sponsored programmes on the irradiation of fruit and fish in the late 1960s. These initiatives, as well as other training courses, conferences and exhibitions, were intensely promoted through the official and unofficial propaganda channels of General Franco's regime in the mid-1960s, and received considerable media coverage. Promotion of nuclear technology had an important ally in the chambers of commerce of Barcelona and Bilbao (capitals of the main industrial regions in this period) that advertised nuclear technology as a highway to the modernisation of the country. Even though these discourses had a limited effect on the actual adoption of nuclear technologies in Spanish industries, they nonetheless played an important role in the establishment of formal degrees in nuclear engineering in Barcelona, Bilbao and Madrid.¹¹²

¹¹¹ Ana Romero de Pablos, and José Manuel Sánchez Ron, *Energía Nuclear en España. De la JEN al CIEMAT*, (Doce Calles, 2001), 154.

¹¹² Francesc X. Barca-Salom, *Els inicis de l'enginyeria nuclear a Barcelona. La Càtedra Ferran Tallada (1955-1962)*, PhD dissertation (Universitat Politècnica de Catalunya, 2002). See also: Francesc X. Barca-Salom, "Dreams and

The success of the establishment of a radioisotope industry can be observed by looking at the rapid increase of the numbers of registered users of radioisotopes, which increased from 150 in 1963 (65% of them working in medicine-related fields) to 1100 in 1973 (50% in medicine). Indeed, a national conference on the applications of radioisotopes (*Simposio Nacional sobre las Aplicaciones de los Isótopos Radiactivos*) was organised in 1967, gathering 172 participants from 88 different institutions. The introduction of radioisotopes in industry in the early 1970s is also evidenced by the de-centralisation of installations, such as the installation of a new irradiation unit in a private firm near Barcelona in 1971, or the establishment of the company Equipos Nucleares SA in Santander for the testing of big nuclear components. In 1976, Spain counted 172 medical users and 529 radioactive installations and the JEN produced radioisotopes in three main sectors: radiopharmaceutical products for medical analysis, carbon-14 and tritium tagged compounds for research, and gamma radiation sources for industrial uses. An important amount of these products were sold to foreign users in the USA, Canada, Australia, New Zealand, India and other countries¹¹³.

2.4.4. The crisis of the JEN and the radioisotopes industry

However, the process of nationalisation of the radioisotope supply seems to lose impetus in the late 60s. Despite claims that isotopes produced in Spain could satisfy all national demand in the 1970s, the part of nationally-produced radioisotopes in relation to total sales gradually diminished since 1968. In the late 1970s sales stagnated as well, and the closing of the JEN-I reactor in 1984 and discontinuation of the CORAL-1 project put an end to national production of radioisotopes.

Nuclear developments in the late 1970s in Spain were characterised by the construction of the first commercial nuclear power plants and the rising contestation of the regime and its economic and energy policies. The JEN was closely connected with institutions supporting Franco's dictatorship – electrical companies and the military - and was a showcase of their modernising policies. Yet at the same time, it suffered from the same defects typical of the regime, such as abuse of secrecy, conflict of interests, highly hierarchic commandment chains and authoritarian decision-making.

Needs: The Applications of Isotopes to Industry in Spain in the 1960s," *Dynamis* 29 (2009), 307–36; Francesc X. Barca-Salom, "Les Aplicacions Dels Isòtops a La Indústria Durant El Franquisme," *Quaderns d'Història de l'Enginyeria* 7 (2006), 1–44.

¹¹³ "Investigación. Estado actual de la utilización médica de radioisótopos en España", *La Vanguardia*, 16.01.1977

The first years of democracy, and especially the first socialist governments, were characterised by attempts to reform the JEN, following a process similar to that in the United States with the AEC. This reorganisation led to the creation of new institutions that took in charge surveillance activities, such as the Nuclear Safety Council (*Consejo de Seguridad Nuclear, CSN*), and the transformation of research facilities into an energy research public body, the Centre for Research in Energetic and Environmental Technologies (*Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT*).

The splitting and downgrading of the JEN coincided with the cancellation of policies aiming at establishing a national supply of radioisotopes. The division of isotopes was dissolved in small groups that developed their expertise in more direct contact with the field of application, such as hydrology. The closure of the JEN-1 reactor, which was mainly devoted to this task, put an uneventful end to these programmes, and Spanish users returned to the practice of acquiring radioisotopes from commercial companies operating in a globalised isotope market.

Regarding public exposure, the uses of nuclear energy for the generation of electricity became much more important than radioisotope applications. At the same time, the arrival of a democratic regime, accompanied by the emergence of a free press, gave rise to a less enthusiastic reporting on JEN accomplishments. If during Franco's regime not one single article critical of nuclear energy may be found in the mainstream press, reports of accidents became far more prevalent after 1977.

2.5. Transnational developments: the case of the IAEA

The International Atomic Energy Agency (IAEA) had a great influence on the development of the radioisotope market and the introduction of norms and standards concerning the entire production and distribution chain, with a particularly strong impact on the developing world (an observation which holds still true today in regard of developing countries). Since its foundation, the number of member-nations has constantly grown from 60 at its founding in 1957 to over 110 members in 1977, and finally 168 members in 2016. In what follows, we briefly describe IAEA's origin and activities, as well as the major cooperation programmes launched throughout the Agency's history¹¹⁴.

The IAEA grew out of Eisenhower's "Atoms for Peace" initiative and, since the late 1950s, profoundly shaped international cooperation in the civil sector of nuclear energy. Its activities were often carried in collaboration (yet not without conflicts) with other major international organisations, most importantly the Food and Agriculture Organisation (FAO), the World Health Organisation (WHO) and the World Meteorological Organisation (WMO). The Agency's initial goal was to control the proliferation of nuclear weapons in the world. According to Statute, its purpose is the achievement of "the more rapid and more widespread utilization of atomic energy for the maintenance of peace, health, prosperity throughout the world, [while also trying to assure that its assistance] would not be used in such a way as to contribute to any military objective"¹¹⁵. One main measure was (and still is) to limit access to strategic resources, in particular uranium, which was thought to be found only in very few areas of the world. The idea was to allow its distribution in limited quantities only to countries with peaceful agendas for use in nuclear power plants. However, since very few nations had power plants at the time, IAEA also took up other roles (also for economic reasons) as for instance the use of radioisotopes as a peaceful application of nuclear energy. This area remained over the course of the Agency's history a major area of its responsibility.

One of the first important programmes established shortly after IAEA's foundation was in the agricultural sector, in close collaboration with FAO. In order to promote nuclear techniques in research on food and agriculture, a joint FAO/IAEA Division of Nuclear Techniques in Food and

¹¹⁴ This section is mostly based on David Fischer, *History of the International Atomic Energy Agency. The First Forty Years*, Vienna: IAEA, 1997.

¹¹⁵ IAEA Statute, 1963.

Agriculture was set up. Through the use of isotopes and radiation, several goals were pursued: improving production of meat and milk, pest control, improving shelf life of food and food safety, fertiliser and water optimisation, controlled crop mutation, as well as pesticide and chemical pathway analysis in the food chain and the environment. In particular the application of radioisotopes in industry nourished during the early Cold War great hopes and IAEA actively pushed their wide distribution. As stated by IAEA's Scientific Advisory Committee in 1966, within the field of industrial applications, services Member States could benefit from important services provided by IAEA:

“a) for developed countries: increased publicity, centralization of information and bibliographies and the stimulus of specialized panels and large scientific meetings;

b) for developing countries: training of personnel; technical assistance, information, modification of existing techniques to fit their particular requirements and accelerate development of new techniques to meet their special needs.”¹¹⁶

As seen above in the case studies, human health also played a leading role from early on, reflected at the very beginning in the actual composition of the *Life Science Division* divided into three sections: nuclear medicine, radiation biology, and dosimetry¹¹⁷. Thus, programmes in the radiation treatment of cancer were set up throughout the world, with staff training and technology procurement supported by IAEA. Dosimetry was another important field of investigation jointly pursued with the WHO, assuring the calibration of nuclear instruments as well as the introduction of international standards in a global network of actors. Finally, nuclear medicine is the most common application of radiation in the human health sector and IAEA actively supported the establishment of nuclear medicine services which are now present in almost all of the Agency's Member States, also in the developing world.

Maybe a less visible but a nonetheless important health-related domain the IAEA set up concerns the Earth sciences and in particular environmental monitoring and research¹¹⁸. Because of growing public concern of environmental pollution, several monitoring networks were established early on in order to trace pollutants in the atmosphere and within the entire water cycle, producing new knowledge on global distribution processes and local ecological

¹¹⁶ IAEA Archives, “The Application of Radioisotopes in Industry and Mineral Resources Development,” 21.11.1966, SAC/INF/15, p.2.

¹¹⁷ IAEA Archives, “Long-Term Programme of the Life Science Division,” 18.12.1967, SAC/INF/20, p.1.

¹¹⁸ IAEA Archives, SAC/INF/15, Appendix I.

cycles. Some global monitoring programmes have been particularly valuable to developing countries such as GNIP, the 'Global Network for Isotopes in Precipitation' established in cooperation with WMO and producing valuable information for water management. Another significant contribution to global environmental research was made via the Global Environmental Monitoring System (GEMS), established with the help of UNEP and WMO in 1975 which allowed the gathering of environmental data on climate, water and human health¹¹⁹.

Finally, IAEA also initiated and financed many training programmes in most of the fields described above. In nuclear medicine for instance, physicians from "developing countries" (these included at the beginning also many East European countries) were sent for mostly one-year training to the United States and Western Europe where nuclear medicine was mostly advanced. In the industrial applications sector, personnel was trained (by the 1990s, a total of 1680 persons) by the IAEA for the use of non-destructive testing techniques, and in Latin America alone, 22,000 workers were trained in national training programmes set up according to IAEA standards which thus became a national ISO standard for personnel qualification. These educational and technical assistance programmes were accompanied by a vast publishing programme in order to allow the free circulation of knowledge of the peaceful uses of nuclear energy, with frequent organisation of workshops and international conferences in order to allow exchange of information.

From the very beginning, the Agency took up two major roles which at times complemented each other and at other moments provoked frictions, namely its regulatory ambitions and the promotion of the peaceful uses of nuclear energy. In general, one can observe that with the multiplication of nuclear accidents (Three Mile Island, Chernobyl and most recently Fukushima) and several breaches of IAEA safeguards agreements, the regulatory role of IAEA has become increasingly important, especially from the point of view of the industrialised nations. Also, several industrialised member states have lost their initial interest in promoting nuclear energy as an energy source, pushing now environmentally safer sources, thus turning the safe decommissioning of old reactors into an area of growing interest.

Although radiation and radioisotopes are not mentioned in the Statute of IAEA (one finds however numerous references to "source materials" and "special fissionable materials"), they were from the very beginning the only serious applications of nuclear science the Agency could

¹¹⁹ IAEA Archives, SAC/142, 04.11.1977, p.6.

promote. In fact, as seen above, they invaded from the very beginning most IAEA science programmes, creating sometimes significant frictions with other specialised agencies which already had set up very similar programmes. However, the resulting jurisdictional disputes were finally resolved in favour of IAEA, mostly because of the low priority of science programmes for the developing countries who guided the interests of the agencies concerned. There is also an important political reason why IAEA still keeps radioisotope programmes running, although not all member states benefit from these programmes in the same way. These programmes can be also seen as a trade-off for the developing countries, because in terms of safeguarding, the power balance is inverted: it favours the nuclear weapons States which are permitted to retain their nuclear arsenal whilst denying access to nuclear weapons to all other States that are party to NPT. The assistance the Agency is giving to the developing countries can thus be seen as a strategy to soften the image of the guardian who serves only the powerful.

Although nuclear science techniques were clearly state-of-the-art when the Agency was founded, its role has shifted over time. For instance, today, nuclear medicine is a firmly established discipline, yet in industrialised countries, the support of IAEA has significantly declined and has no impact anymore on the availability of these technologies. This holds however not true for developing countries. There, the IAEA still plays an important role and it is an important source of aid, be it in terms of financial, physical or intellectual capital, which has grown historically out of the programmes mentioned above.

3. Conclusion

In the previous section we have analysed the development of the radioisotopes industry in four different European countries and the activities of transnational nature due to the International Atomic Energy Agency. As we have seen, the cases show the diversity of appropriations of radioisotope technology in these countries. However, what is more remarkable is the similarity of institutionalisation processes and representations, which allow for a common periodisation and some generalisations.

First, the cases studied show that radioisotopes were essential constituents of all nuclear programmes in its early phases. In the four cases studied, the period 1950-1960 can be considered as the founding stage of radioisotope industries. In this phase, radioisotope production was firmly embedded in state-controlled institutions, generally research centres of national atomic energy establishments. With the exception of Germany, whose nuclear programme was limited at the very beginning by post-war restrictions, the institutionalisation of radioisotope production and research generally mimicked the model adopted in the United States, that is, the establishment of a centralised body (generally called “isotope division”) in charge of a distribution programme, the broadening of expertise by means of training courses, and the introduction of safety regulations.

Radioisotope production was initially very closely related to military programmes, and subject to secrecy and strict regulations. The American “embargo” of radioisotopes, related to national security concerns, allowed room for the expansion of European initiatives, especially in the United Kingdom, paving the way for the emergence of Amersham as a key player in the market. These regulations were softened by the Atoms for Peace initiative, which eased the circulation of expertise, materials and instruments in relation to radioisotopes, as a counterpart of limiting nuclear proliferation in military-related fields. However, East/West exchanges were still de facto limited until the 1970s.

In this early period, radioisotopes played an important role in the legitimisation of nuclear projects in society. By following the American model, European nuclear establishments multiplied the exhibitions, press releases and other means of promotion which advertised the benefits of radioisotope applications, and especially its medical uses. By counteracting the military aspect of nuclear technology, these campaigns also linked nuclear technology with the modernisation

and the reconstruction of Europe after the Second World War. Widely advertised in the media, the applications of radioisotopes became central elements of the nuclear energy imaginary, involving images such as the reactor as the crucible of modern society. The extension of isotopes to these areas was only possible because distribution programmes were not constrained by the market. Huge investments of political and financial capital created an economy of isotopes which effectively subsidised radioactive materials disregarding true production costs and ignoring patent rights under the secrecy of national security considerations¹²⁰.

At the same time, the introduction of nuclear establishments was generally a “national” endeavour, which linked national identity with this modernising endeavour. This was especially true for countries such as France and the United Kingdom, in which nuclear technology was constituted as a source of national independence. In contrast, in countries under authoritarian rule such as Spain or the German Democratic Republic, the role of nuclear technology as provider of international collaboration was emphasised.

The exploration of multiple applications of radioisotopes thus accompanied the growth of nuclear programmes and the construction of research reactors peaked in the 1960, with almost 300 research reactors built in this decade worldwide. For medical applications, the pattern generally adopted involved a division of labour between nuclear agencies, which produced radioisotopes, and private radiopharmaceutical companies, which assumed intermediary roles such as processing, packaging, transport, and supply to hospitals¹²¹.

In the 1970s and 1980s, the radioisotope industry entered a period of normalisation, in which the IAEA assumed an important role in the coordination of research and development, standardisation, control and safety measures, and training. International laboratories such as Seibersdorf led the application of radioisotopes in agriculture and the transfer of these techniques to developing countries. Collaboration between Eastern and Western countries was also fostered in a context of “détente” and European integration.

The 1970s also saw the emergence of Molybdenum-99 / Technetium-99 as the most important radioisotope in diagnosis and imaging, attaining approximately 80-90% of the market share of radioisotopes. The expansion of the use of this isotope took place in a context in which

¹²⁰ Néstor Herran and Xavier Roqué, “Tracers of Modern Technoscience”, *Dynamis* 29 (2009), 123–130.

¹²¹ Jim Green, *Reactors, Radioisotopes & the HIFAR Controversy*, PhD dissertation (University of Wollongong, 1997).

pharmaceutical companies consolidated and expanded the radioisotope market, developing new tools for diagnostic and imaging, as well as global supply chains. In a market that remained quite modest in size, this process was accompanied by the discontinuation of production in many countries, the establishment of new research reactors becoming increasingly rare. Whereas 274 research reactors were installed in the 1960s, only 84 were built in the 1970s and merely 35 in the 1980s¹²². The number of countries producing radioisotopes diminished and, since the 1980s, the radioisotope market progressively concentrated in a few companies. For example, in the 1990, Canadian company Nordion supplied almost all Mo-99/Tc-99 worldwide.

This process of concentration and globalisation of the radioisotope market, which was accompanied by the privatisation of leading state-owned companies such as Amersham, passed relatively unnoticed in public opinion. In contrast to the situation in the 1950s and 1960s, when radioisotopes attracted much media attention, news on nuclear medicine and radioisotope-related research became less prominent, with mention of radioisotopes in the press being often related to contamination episodes during nuclear accidents (see figure 9).

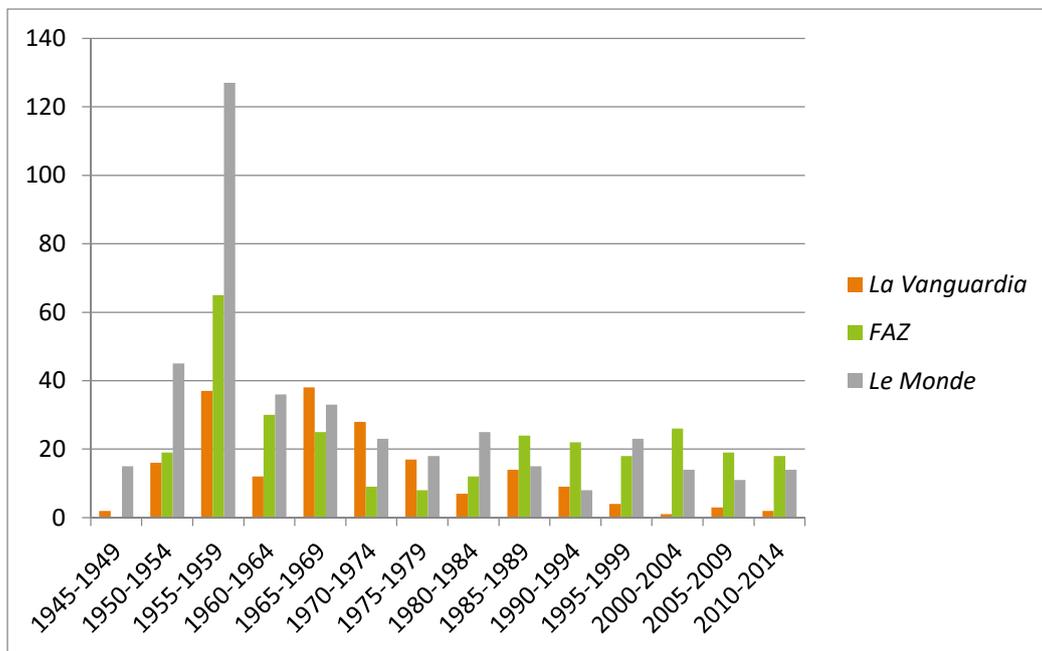


Figure 9: Coverage of radioisotopes in a selection of French, German and Spanish newspapers, 1945-1914¹²³.

¹²² Ibid, p. 245.

¹²³ The chosen newspapers (*Le Monde* for France, *Frankfurter Allgemeine Zeitung* for Germany; and *La Vanguardia* for Spain) are representative of conservative, widely circulated and broad in scope newspapers, counting with Web-based historical databases.

Since the 1990s, the diminishing number of research reactors because of decommissioning and lack of investments, together with an increasingly concentrated radioisotope industry has dissociated the growth of the nuclear industry from the radioisotope market. International institutions such as the Nuclear Energy Agency of the OECD criticise the entire economic structure of the isotope market, claiming it is biased, with a private sector not paying realistic production costs and governments subsidising a sector that is not economically viable on the long run¹²⁴.

Finally, in terms of social acceptance, one can note that whereas the 1970s saw in France – just as in many other European countries – the rise of a strong antinuclear movement, this movement lost a lot of its steam and it seems that today, large parts of French society have come to terms with the nuclear sector, maybe partly because it was reinvented as an “effective” response to climate change, an efficient “ecological”, “renewable” energy source¹²⁵. The radioisotope market could clearly benefit from this development, rarely being the subject of social protest. However, environmental organisations continue to fight against the installation of new experimental research reactors (such as the ITER project in Cadarache) not only on environmental, but also on economic grounds¹²⁶. The future will show how the most nuclearised of all countries will deal with these profound tensions. Even though there might not be an ecological rethinking in the near future, the economic argument surely will prove to have important consequences as the entire radioisotope market requires a profound makeover.

¹²⁴ Nuclear Energy Agency, *The Supply of Medical Radioisotopes. An Economic Study of the Molybdenum-99 Supply Chain* (NEA, 2010).

¹²⁵ Sezin Toçtu, *La France nucléaire: L'art de gouverner une technologie contestée* (Seuil, 2013).

¹²⁶ “Les associations de protection de l’environnement condamnent le projet,” *Le Monde*, 28.06.2005.

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