Isotope networks: Training, sales and publications, 1946-1965

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SUMMARY: 1.—Introduction. 2.—The isotope market. 3.—The isotope workforce. 4.—Publications. 5.—Conclusion.

ABSTRACT: The aim of this paper is to provide an assessment of the spread of isotope-related techniques in Western Europe and the USA in the two first decades after World War II, by focusing on structural features. In particular, I analyse three major components of the European «isotope industry»: radioisotope distribution networks, the establishment of training sites and publications in which isotopes played some role as the object of study or research tools. This study leads to an assessment of the importance of industrial applications of isotopes in this period, in relation to biomedical ones, and provides with a transnational comparison in terms of productivity in material resources, workforce and knowledge.

PALABRAS CLAVE: Aplicaciones industriales de isótopos, enseñanza, publicaciones, mercado de isótopos, historia de la Ciencia comparada.

KEY WORDS: Industrial applications of isotopes, training, publications, market for isotopes, comparative history of science.

1. Introduction

From the late 1940s to the mid 1960s, isotope techniques and biomedical sciences fostered each other as part of a symbiotic relationship. On the one side, the application of isotopes to biological research and cancer therapy helped to counteract public concerns about the military side of nuclear technology. On the other, the isotope distribution programmes provided more funding and new tools for advancing fundamental research. This strong association has been analysed by historians of science, who have shown the overlapping of scientific and industrial policies, ideology, diplomacy, techno-scientific knowledge and the public image of science in nuclear programmes.

As part of this picture, biomedicine remains a clear-cut object of analysis and an interpretative adage. Biomedical research provided the initial impetus and accounted for most isotope users. At the same time, medical therapy was portrayed as the most important achievement of nuclear programmes, helping to construct the image of the «peaceful atom» even before the Geneva conference. Indeed, isotope science and distribution programmes could be seen as preceding current large scale biomedical research, pioneering the introduction of «Big Science» in life sciences.

Recent interest in biomedical applications of isotopes has however shadowed other applications, such as industrial ones. From the late 1940s to the mid 1960s, a number of industrial applications of isotopes were designed and developed either as instruments for industrial research laboratories or specialised machinery in factories. To give a few examples, isotopes were used as tracers for studying the structure, fabric, corrosion and durability of metals; for obtaining radiographies of metal structures; as probes in oil prospecting devices; as irradiation sources for chemical processes; as measuring and gauging devices, or as ionising sources in apparatus for static electricity elimination.

In this article, I comparatively analyse the isotope programme in industry and biomedicine. In doing so, I do not aim to minimise the importance of biomedical perspectives, but to complement them. For example, Angela Creager has claimed that we should consider isotope sciences as a case of interstitial research technology laid out within a process of industrialization of isotope production and distribution [1]. This view, combined with a whole appreciation of nuclear technology as a techno-scientific system, is a good starting point for critically evaluating the impact of such techniques in contemporary industry, and taking into account the persistent military and political correlations of the whole enterprise.

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1. Angela N. H. Creager. The industrialization of radioisotopes by the U.S. Atomic Energy Commission. In: Grandin, Karl; Wormbs, Nina; Widmalm, Sven, eds. Science and industry in the 20th century. Sagamore Bearch, MA: Watson Publishing; 2004, p. 141-168. On research technologies, see Rheinberger, Hans-Jörg. Putting isotopes to work: Liquid scintillation counters. In: Joerges, Bernward; Shinn, Terry, eds. Instrumentation: Between science, state, and industry. Dordrecht: Kluver; 2001, p. 143-174.

I have chosen some key features of the expansion isotope sciences as the starting point for my study: the distribution of radioactive materials, the establishment of training programmes and the growth of publications related to isotope research. I confine my investigation to the first twenty years of nuclear programmes (1945-1965), which can be considered the «Golden Age» of isotope sciences. I will only study in detail the developments of these three aspects in three western nuclear powers: the United States, the United Kingdom and France. The study, however, provides us with a good picture of the spread of isotopes internationally.

2. The isotope market

A good starting point for determining the scope of isotope-based industrial research is to look at the proportion of the isotope market related to these applications. To perform such an analysis, we first have to consider three main features of this market: the purposes behind its creation, its international structure and the detailed sales of particular isotopes. Of these three topics, the first has been the most conspicuously addressed in recent historical literature. This is the focal point of Timothy Lenoir and Marguerite Hays study of the United States' isotope distribution programmes [2], of Alison Kraft's analysis of the British isotope distribution programme and its relation with the medical establishment [3], and of Angela Creager's study of the political tensions affecting the international distribution of isotopes [4]. In this historical framework, the motivation of isotope programmes appear to be the result of three main forces: the previous momentum of isotope research (which defined the personal agendas of scientists working in the field), the interest in providing a «peaceful image» of nuclear science, and

2. Lenoir, Timothy; Hays, Margherite. The Manhattan Project for Biomedicine. In: Sloan, P. R., ed. Controlling our destinies: Historical, philosophical, ethical, and theological perspectives on the Human Genome Project. South Bend, IN: Notre Dame Press; 2000, p. 19-46.
3. Kraft, Alison. Between medicine and industry: Medical physics and the rise of the radioisotope 1945-1965. Journal of Contemporary British History. 2006; 20: 1-35.
4. Creager, Angela N. H. Tracing the politics of changing post-war research practices: the export of «American» radioisotopes to European biologists. Studies in History and Philosophy of the Biological and Biomedical Sciences. 2002; 33: 367-388. See also Angela Creager's paper in this volume.

the internal agendas of scientists in the transition from wartime to post-war scientific research.

By the mid-1940s, isotope sciences were already considered an important and promising field. In the 1930s, new isotope production instruments such as the cyclotron, and the availability of private research funds had fostered research programmes for applying the methods of physical sciences to biomedicine. This environment promoted the emergence of centres such as the department of Biological Chemistry at Columbia University, where Rudolf Schoenheimer studied fat metabolism with Nitrogen-15; the Niels Bohr Institute at Copenhagen, where Georg Hevesy studied the absorption of phosphorus by plants with Phosphorus-32, or the Berkeley Radiation Laboratory, where Martin Kamen and others investigated the mechanism of photosynthesis with Carbon-11 [5].

The perceived relevance of such research to the fight against cancer led to the emergence of an influential community of practitioners, which were promoted to the highest ranks of the scientific elite. From the mid-1930s to mid 1940s, Nobel Prizes were awarded for discoveries related to the study, production and use of isotopes: Harold Urey (1934), for his discovery of heavy hydrogen; Frédéric Joliot and Irène Curie (1935), in recognition of their synthesis of new radioactive elements; Enrico Fermi (1938), for his demonstrations of the existence of new radioactive elements produced by neutron irradiation; Ernest Lawrence (1939), for the invention and development of the cyclotron and for results obtained with regard to artificial radioactive elements, and Georg Hevesy (1943), for his work on the use of isotopes as tracers in the study of chemical processes [6].

During the Second World War, research within the Manhattan project led to the creation of an important community of specialists in the study of the effects of radiation on living organisms. After the war, most of these

5. On Hevesy's research, see Gabor Pallo's article in this same volume. On Schoenheimer's work, see Kohler, Robert E. Rudolf Schoenheimer, Isotopic tracers and Biochemistry in the 1930s. Historical Studies in the Physical Sciences. 1977; 8: 257-298. Hevesy's research in Copenhagen is described in Aaserud, Finn. Redirecting Science. Niels Bohr, Philanthropy and the rise of Nuclear Physics. Cambridge: Cambridge University Press; 1990. On Berkeley's experiments, see Heilbron, John L.; Seidel, Robert. Lawrence and his laboratory. A history of the Lawrence Berkeley laboratory. Berkeley: University of California Press; 1989. Kamen's experiments are vividly recounted in his autobiography: Kamen, Martin D. Radiant science, dark politics: A memoir of the Nuclear age. Berkeley: University of California Press; 1985.
6. On the presence of nuclear sciences in Nobel Prizes, see Hughes' article in this same volume.

were integrated into the system of national laboratories and promoted isotope research in the United States. Such a programme was sustained on the grounds of its perceived utility in the fight against cancer, but also because of its dual role regarding the nuclear programme: on the one side, it was considered a peaceful alternative to the nuclear military project; on the other, it helped to justify it.

The first shipment of isotopes within the distribution programme was made on August 2, 1946, almost exactly a year after the first use of the atomic bomb on Hiroshima. In contrast with the destructive effects of the atomic bomb, the medical utility of isotopes was emphasized, helping to launch the United States' isotope distribution programme. This programme was established on the premise of the scarce availability of isotopes worldwide. The allocation was based on the adoption of «the principle of maximum benefit, in the way of scientific result, with minimum material». Accordingly, basic physical and life sciences were «given preference over all other uses, including the applied sciences of medicine and engineering» [7].

However, this schema was soon surpassed with the expansion of Oak Ridge, the United States AEC's most important production facility. By 1948, isotopes had become a powerful impetus and justification for the whole AEC programme. A contemporary report on the recent scientific and technical development of the atomic programme, published by the recently established Atomic Energy Commission, described isotopes as a foremost contribution to the welfare of humanity:

> «Isotopes for scientific, medical, agricultural, and industrial use constitute the first great contribution of atomic energy to peacetime welfare. Industrial power from nuclear energy may be a decade or longer in the future (...), and most other applications are still largely speculative. But isotopes produced in the Nation's atomic energy establishment at Oak Ridge, Tennessee, are already at work in more than 300 laboratories and hospitals in this country and abroad, adding to man's store of knowledge about himself and the world around him (...) as tracers, they are proving themselves the most useful new research tool since the invention of the microscope in the 17th century;

7. Warren, Colonel S. Specific proposals for the national distribution of radioisotopes produced by the Manhattan Engineer District. January 3 1946; p. 3. This information was collected via internet from the Human Radiation Experiments Archives (HREX) available at the Department of Energy OpenNet System: https://www.osti.gov/opennet/ [accessed Nov 28 2008].

> in fact, they represent that rarest of all scientific advances, a new mode of perception [8].

The USAEC reports depicted isotope research in overwhelmingly positive terms, claiming that «if the development of atomic energy had produced nothing else, its cost would undoubtedly have been balanced within a few years by the gains in knowledge that the Nation is making with isotopes» [9]. This happened even when the USAEC General Advisory Committee produced a somewhat more pessimistic forecast about the possibilities of obtaining electricity from nuclear energy. In 1948, the committee described the difficulties for obtaining energy from reactors, estimating it would be 20 years before an effective source of energy was developed [10].

With isotopes at centre-stage, and production accelerating, industrial applications were considered as promising as biomedical ones. The AEC aimed to convince industrial firms (especially instrument manufacturers) to join the programme:

> «the businessman has reason to be interested in isotopes. Their utilization in scientific research has created a demand for new kinds of equipment and services which will continue to grow very rapidly in the years ahead. Their application to industrial problems opens an immense field for future development. (...) With the Commission furnishing the basic pile-produced isotopes required for the manufacture of radioactive compounds, private industry is in a position to provide all of the equipment, materials, and services needed by isotope tracer laboratories today. Already, electronic firms have taken the lead in developing radiation detection instruments. (...) firms going into this field are looking beyond today's market, in which 8 out of 10 isotope research projects are concerned with basic science, fewer than 1 out of 10 with industrial problems. Of course, the supplying of laboratories and hospitals can be

8. US Atomic Energy Commission. Recent Scientific and Technical Developments in the Atomic Energy Program of the United States. Washington DC: US Government Printing Office; 1948, p. 5. About 60 percent of the report, plus 110 pages of appendixes, were devoted to isotopes.
9. US Atomic Energy Commission. Third Semi-annual Report of the United States Atomic Energy Commission. Washington DC: US Government Printing Office; 1948, p. 7.
10. US Atomic Energy Commission. Recent Scientific and Technical Developments in the Atomic Energy Program of the United States. Washington DC: US Government Printing Office; 1948, p. 43. Committee members were Robert Oppenheimer, James B. Conant, Lee DuBridge, Enrico Fermi, Isidor Rabi, Hartley Rowe, Glenn Seaborg, Cyril S. Smith and Hood Worthington.

> a good-sized business in itself. But the potential application of isotopes to the work of industry –for the control of processes, the testing of products, and the development of entirely new processes and products- is an open field of opportunity. It is the kind of field that American competitive industry is uniquely fitted to develop» [11].

By late 1948 more than 30 industrial organisations were already using radioisotopes in research and development programmes. Among others, Goodyear Tire and Rubber used isotopes in developing thickness gauges; the Industrial Radiography Laboratory used Co-60 for industrial radiography, and Edward S. Gilfillan Jr. Consulting, used Sr-89 to eliminate static electricity from textiles [12].

But, how important were these applications as part of the isotope programme as a whole? If we look at the sales of isotopes, it seems like industrial applications were less important than biomedical ones. In the first five years of the isotope distribution programme (1946-1950), the AEC sent 11,400 domestic shipments of radioisotopes, of which 5161 (45%) were used in medical therapy, 2920 (27%) in animal physiology research and only 427 (3.7%) in industrial research. Iodine-131 and phosphorus-32 alone accounted for about two thirds of all cumulated sales [13].

However, both I-131 and P-32 are light, short-lived isotopes, with half-lives of only 8 and 14 days respectively. Thus shipments were sent on a regular and periodical basis. On the other hand, isotopes employed in industry had a longer half-life and were used repeatedly after the shipment. In this sense, the abundance of biomedical shipments can be misleading. USAEC reports reveal that by 1953 sales of isotopes remained stable, with I-131 and P-32 accounting for about 64% of the total sales.

11. US Atomic Energy Commission. Recent Scientific and Technical Developments in the Atomic Energy Program of the United States. Washington DC: US Government Printing Office; 1948, p. 35-36.
12. The isotope-based thickness gauge was based on the measurement of flux variation after beaming rays across the material. Static electricity was eliminated by using the isotope as an ionization source. US Atomic Energy Commission. Recent Scientific and Technical Developments in the Atomic Energy Program of the United States. Washington DC: US Government Printing Office; 1948, p. 114-116.
13. US Atomic Energy Commission. AEC Eighth Semi-annual Report. Washington DC: US Government Printing Office; 1950. p. 195. In the same period, 813 shipments were sent abroad, of which 71% were shipments of P-32 and I-131.

But industry was a major user of radioisotopes. Of 1958 registered users, 774 were industrial firms (42% of all users), whereas medical institutes and physicians accounted only for 34% of all users (and they could have even included a high proportion of individual physicians) [14].

Although industrial applications of isotopes were not as publicly prominent as those related to biomedical research and therapy, they played an important role in the projects of AEC administrators. And one of the reasons that halted the US distribution of isotopes abroad was precisely the fear that the exports could foster the industrial development of the Soviet Union. A consequence of these fears was the *de facto* embargo imposed on the export of American produced isotopes until mid-1947. The embargo acted as an additional stimulus to rival isotope distribution programmes in other nations. Among them, the most prominent was the British, created by the Atomic Energy Research Establishment (AERE). Based on the nuclear reactors built under the military-oriented United Kingdom nuclear programme, the British isotope distribution programme developed very efficiently, and had even surpassed the United States in terms of the number of shipments by 1951 (see Graph. 1) [15].

The United States and the United Kingdom isotope distribution programmes were organised in a very similar way, with isotope divisions taking charge of the production and allocation of reactor-produced isotopes. However, their markets were configured very differently. In 1953, while 93% of American shipments were sent to recipients in the United States, Britain exported about 40% of its production to other countries. By then, the United Kingdom was the main provider of radioisotopes in the Western World, having established commercial contacts with institutions and nuclear

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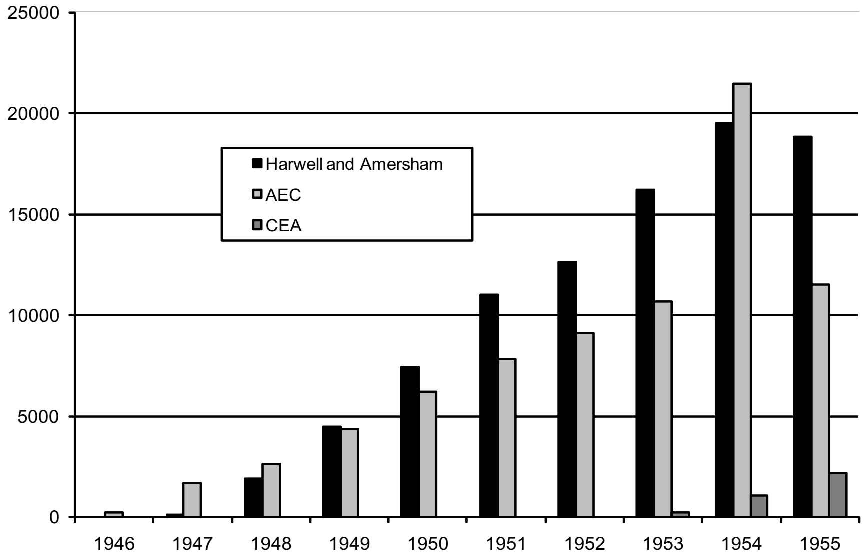
14. US Atomic Energy Commission. AEC Fifteenth Semi-annual Report. Washington DC: US Government Printing Office; 1953, p. 94. A more clear comparison can be made with data from 1955. By then, medical therapy accounted for 47% of all shipments, while industrial research only for 4%. Nevertheless, industry accounted for 42% percent of users, and hospitals and private physicians were only 38%. In this year, there were about 450 firms doing radiographic tests and 425 firms using radioactive gauging.
15. Another reason for the success of the British initiative could have been their more relaxed system for allocating isotopes, which contrasted with the controls established by the United States. On the American embargo of isotopes, see Angela Creager's paper in this volume.

Graph. 1. Isotope shipments sent by the USA, the UK and France, 1946-1955[16].



establishments in at least 30 countries[17]. The success of the AERE Isotope Division can be partially explained by its more flexible system of isotope allocation involving less security clearances than the US (for example, Britain never requested reports on research made with the isotopes)[18], commercially competitive prices[19], and a fast delivery system, which was crucial to take a large share of the European market of short lived isotopes

16. Data on the isotope distribution and exports in Harwell for the period 1947-1951 has been compiled from two UKAEA sponsored reports: Jay, Kenneth E. B. Atomic Energy Research at Harwell. London: Ministry of Supply; 1955, p. 27 and Harwell. The British Atomic Research Establishment, 1946-1951. London: Ministry of Supply; 1952, p. 27. Similar data on the United States shipments came from the AEC Semi-annual reports. Data on French shipments came from CEA Annual Reports. In using this data, however, we should take into account the fact that the statistics did not reflect the total amount of radioisotopes (by curies, or doses, for example) sent: they only reflect the number of shipments.
17. This tendency continued even after the Geneva conference. In 1956, Britain exported more than 50% of its production, while the United States was selling only 9% abroad.
18. See Angela Creager's article in this same volume. From September 1954, the AEC changed the requirements for the submission of reports. From this moment, they should only be furnished upon specific request to the AEC.
19. Prices of British-produced radioisotopes were established with reference to AEC isotope catalogues. On pricing, see UK National Archives. File AB 6/553.

such as I-131 and P-32. Finally, patent issues plagued the full development of the US programme, and could have also had some impact on Britain moving forward in this field [20].

The AERE, like its American counterpart, also tried to develop the industrial market of radioisotopes. One of the first problems addressed was static electricity, launching collaboration between the Radiochemical Centre and the Textile Research Association. Beta thickness gauges were also developed and exhibited at the British Industries Fair of 1949 [21]. By 1950, 36 companies had used isotopes made at Harwell [22]. The use of thallium for static electricity elimination was one of the key applications for most of them. However, as shown in the internal reports of the isotope division, industrialists were still 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 suggested publicising industrial uses in collaboration with the Department of Scientific and Industrial Research, publishing of monographs about tracer experiments and health manuals for industrial users, the design of simplified counting apparatus at reduced prices and the establishment of training facilities in tracer techniques for industrial scientists [23].

Another initiative to promote industrial research was the Isotope Advisory Service, 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 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 received each year. The physics group carried out research on the uses of isotopes in industry and

20. See Simone Turchetti's article in this same volume.
21. Henry Seligman. Isotope Division 1948-1951. A true report of its failures and successes. November 27, 1951. UK National Archives. File 6/657.
22. Among the companies mentioned were Rizla, Pretrocarbon Ltd., British aeroplanes and BBC. K. Fearnside. Report of uses of radioisotopes in industry, by the Isotope Division. UK National Archives. File AB 6/1290.
23. Fearnside, n. 22. On the training scheme, see next section.

sent their personnel to company premises to investigate and solve their problems [24].

The promotion of the use of isotopes in industrial research was a shared concern of the most advanced nuclear projects, and partially reveals the relative importance of this area amidst the nuclear programme as a whole. However, to understand the scope of the deployment of early nuclear technology, we have to take into account another less material aspect. In the following section, rather than discussing materials and instruments, I want to draw attention to another aspect of this process: the training of experts on the manipulation of radioisotopes.

3. The isotope workforce

The training of scientists and technicians in radioisotope techniques is a facet of the isotope industry that has been studied much less than distribution programmes. Here, I can only quote my own study of the Isotope School at the British AERE [25]. This school, which was founded in Harwell in 1951, became the major training site on isotope techniques in Europe. By 1960, it had trained «over 2000 students from 58 nations (...) from recent graduates to professors and heads of research, and that represent all branches of technology and experimental science» [26]. This experience had been preceded by two similar projects associated to national nuclear programmes. In the USA, the first training courses on isotope techniques had been established at Oak Ridge in 1948. In France, the Comissariat à l'Energie Atomique (CEA), together with the Centre National de la Recherche Scientifique, founded the courses at the Institute Curie in 1950. From 1955, the CEA adopted a more similar model to Oak Ridge, setting up a school in their facilities at Saclay.

Nuclear agencies established isotope schools with different objectives in mind. First, they could help to train some of the scientists working at

24. Functions, grades and numbers of those in the Isotope Division on 11th June 1956. UK National Archives. File AB 6/1739.
25. Herran, Néstor. Spreading Nucleonics: the Isotope School at the Atomic Energy Research Establishment, 1951-1967. British Journal for the History of Science. 2006; 39: 569-586.
26. UKAEA Isotope Division. Report on the Isotope School. April 1960. UK National Archives. File AB 6/1974.

nuclear establishments and national laboratories, which were handicapped by a critical lack of trained personnel. Second, they helped to counteract concerns about the capacity of biologists and physicians to use isotopes as research tools. An example of these concerns can be found in the first AEC reports, which stressed the «severe shortage throughout the scientific world of men able to use them effectively and safely», and criticised notebooks for being «full of useless data». According to them, «the correct interpretation of data demands some grounding in nuclear physics and electronics» [27]. Last, but not least, isotope schools were considered an interesting vehicle for introducing radioisotopes to factories and industrial laboratories. In this sense, it was expected that courses could help to defuse resistance from industrialists (some sceptical about the utility of isotope technology); resolve health concerns and introduce a new isotope-based instrumental culture [28].

The high attendance of the courses and the diversity of students involved clearly show that different motives were at play. From 1948 to 1955, Oak Ridge had trained about 2700 scientists. In the same period, 600 students had joined Harwell Isotope School's courses, while the French CEA-CNRS programme hosted about 400. The structure and duration of all these courses was similar: they were held for about 4 weeks, and combined theoretical lectures with laboratory work. This structure was attractive not only to young students, as a first step in a scientific career using isotopes, but also to senior scientists, who used the stay to make their first contact with new methods and instruments. Attendance figures show that chemists and physicians were in the majority, closely followed by physicists and biologists. However, the disciplinary origin was as varied as the institutional one, and no institution or discipline was absolutely dominant (see Table 1). In this sense, isotope schools were highly heterogeneous places, where connections between different domains could easily be put into action.

27. US Atomic Energy Commission. Recent Scientific and Technical Developments in the Atomic Energy Program of the United States. Washington DC: US Government Printing Office; 1948, p. 17.
28. It is revealing in this sense that nuclear establishments developed close ties with instrument manufacturers, encouraging them to develop nucleonic instruments and inviting them to courses. For a more detailed analysis of these ties, see Herran, n. 25.

Table 1. Origin of the students that attended nuclear establishments' isotope courses

Institution of origin	*Oak Ridge* (1)	*Harwell* (2)	*CEA-CNRS* (3)
Colleges and universities	30%	33%	11%
Hospitals, medical schools	29%	8%	20%
Industry	12%	25%	15%
Research institutions, army, nuclear establishments	26%	24%	26%
Foreign	3%	10%	15%
Students/year in general courses (first five years)	192	125	68
Students/year in all courses (first five years)	300	162	68

Source: (1) ORINS Annual Report, 1952. (2) Report Position of Isotope School at September 1st 1957. UK National Archives. File AB 6/1974. (3) Archives Joliot-Curie, Box I-12.

The aims of isotope schools were congruent with the objectives of the nuclear programmes. However, their situation within national and military-oriented institutions raised security concerns. We have already commented on the security obstacles in relation to the export of isotopes. Courses were affected in a similar way, restricting the attendance of the citizens of «dangerous» or «enemy» nations and even suspect nationals. In the United States, the McMahon Act required the investigation of personnel related to the nuclear programme, and by 1948 the FBI had completed 40,000 inquiries into the «character, associations and loyalty» of AEC staff [29]. In the Oak Ridge facilities, foreigners from allied countries were admitted from 1949, but they were always a small minority. The proportion only increased from 1955, when specific courses for foreigners were introduced.

29. US Atomic Energy Commission. Third Semiannual Report of the United States Atomic Energy Commission. Washington DC: US Government Printing Office; 1948, p. 2.

Table 2. Foreign students in different isotope courses, by geographical area [30]

	Period	*Western Europe*	*America*	*Asia*	*Africa Oceania*	*Eastern Europe***	*Total*	*% of all students*
Oak Ridge	1948-1955	38	43	30	9	0	120	5%
CEA-CNRS	1950-1955	37	13	3	2	7	60	15%
Harwell*	1951-1955	131	10	15	15	2	173	40%

* Only general course; ** Only students from Yugoslavia
Source: See note 31.

As we can see in the table above, foreign attendance on British courses was much higher, reflecting the more international scope of their isotope distribution programme. This same observation applies to the CEA, which admitted a high proportion of foreign scientists since the beginning of its courses. Noticeably, the students' origin reflected bilateral diplomatic relations. Accordingly, students from Eastern Europe were systematically excluded from the Harwell courses, whether for explicit or inexplicit reasons [31]. This situation only changed after the Geneva conference, when initiatives for international cooperation in the nuclear domain fostered international exchanges of students. Indeed, at least in Britain, some limited participation of Eastern European students was allowed.

By then, isotope schools had accomplished some of their main tasks, and were leading to broader training systems. Nuclear medicine had become established as a discipline in most countries, biomedical research was routinely employing isotopes in their experiments and radioisotopes were increasingly employed in industrial settings. Isotope schools were considered an important element in this extension. To give an example, by 1962, a survey of former students of the Harwell Isotope School revealed that 88%

30. Data on Oak Ridge courses comes from ORINS Annual Reports. Attendance of French courses has been reconstructed from the Archives Irene and Joliot Curie, Box I-12. There is no register of Harwell Isotope School students, and data has been reconstructed from the course pictures, stored in the UKAEA archives.
31. For example, the British Isotope School administration used to say that courses were «fully booked up for some time to come» to reject Eastern Europe applications. See Herran, n. 25.

of them were using radioisotopes, and that «although manufacturers were reluctant to produce precise figures, it was evident that we had stimulated sales considerably». Training done at schools claimed a portion of the credit for the economic advantages of radioisotopes in industry [32].

At the same time, courses on isotope techniques were becoming a minor element of the greater system of nuclear engineering education. By 1962, in Britain alone, courses on nuclear engineering had been established in 36 institutions, and 28 of them included isotope technique courses. In Europe, the number of such courses also rocketed, and this same year the OCDE published a catalogue of more than 225 educational institutions offering courses on nuclear engineering, with about two thirds of them offering training on isotope techniques [33]. As some of the lecturers on such courses had been involved in the previous isotope schools, the importance is clear of the role of such early initiatives as a catalyst in the emergence of the workforce in the nucleonic industry, as well as the institutions allowing its future expansion.

4. Publications

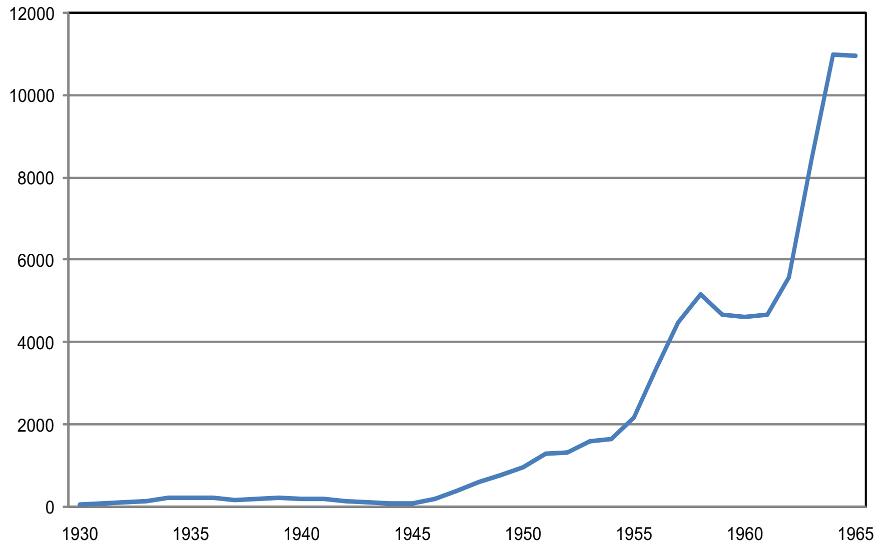
The third and last element I want to analyse here in relation to industrial uses is the evolution of isotope-related publications from the late 1940s to mid 1960s. Historians have by and large neglected this topic. Here, the canonical reference is literature surveys made by scientists involved in the area. A frequently quoted study is Engelbert Broda's compendium, which shows the impact of isotopes in biological sciences by statistically surveying articles discussing isotope techniques in 1945 and 1956. Broda concluded that a growth in the interest in these techniques could indeed be clearly seen. For example, they are mentioned only in 1% of the *Journal of Biological Chemistry* articles of 1945, whilst 39% of the articles in 1956 covered this

32. Report included in Faires, RA letter to: Coulbeck, AG. January 18, 1963. UK National Archives. File AB 6/2424.
33. Germany, the United Kingdom, Italy, France, Belgium and Netherlands were the countries with the most institutions involved in nuclear engineering, accounting for 50% of such institutions in this catalogue. European Nuclear Energy Agency. Catalogue of courses on nuclear energy in the European countries of OECD. OECD: Paris; 1962.

subject[34]. Here, I complement Broda's analysis by looking at the evolution of isotope-related publications in the general scientific literature.

A good starting point for this analysis is the Chemical Abstracts database, which covers the main scientific periodicals related to chemical and physical sciences, and also most of those devoted to engineering and biomedicine. The handling of this vast amount of data requires certain methodological precautions. For example, when plotting the absolute number of articles, the criteria for including an article in this category are that it should incorporate the word «isotope» in the title or abstract, or as a keyword. This criterion can be considered too broad, but avoids missing any relevant part of the literature, such as those related to the use of isotopes as research tools.

Graph. 2. Published articles indexed in Chemical Abstracts dealing with isotope sciences, 1930-1965

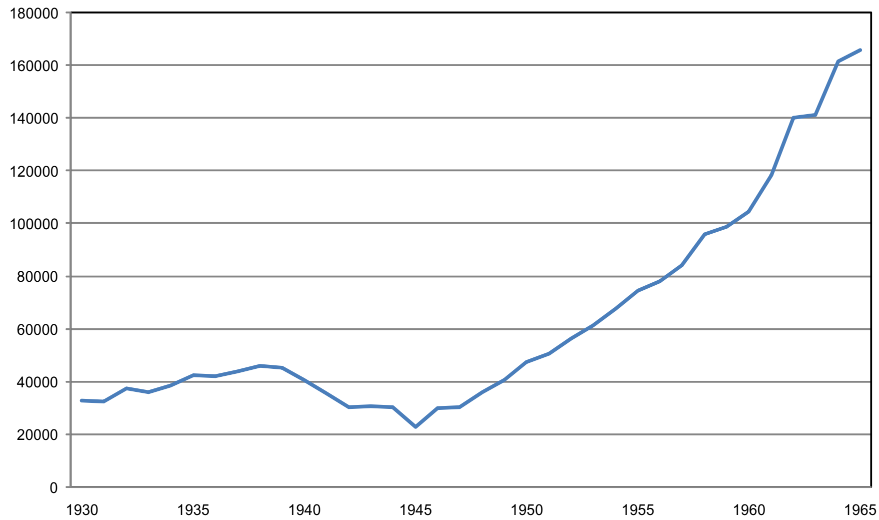


34. Broda reported less prominent increases in the British Biochemical Journal (from 0% to 17%) and the German *Biochemische Zeitschrift* (from 0% to 7%). Engelbert Broda. Radioactive isotopes in biochemistry. Amsterdam; New York: Elsevier; 1960.

Graphic 2 helps to visualise the extraordinary explosion of isotopes after World War II. From an average of 170 articles per year in the 1930-1939 period, isotope sciences attained 1100 papers/year from 1945-1955, and boomed to 6300 articles/year in the 1950s. However, we might ask how important this growth was. Was it a simple increase from the 1930s? Or did isotope sciences simply mimic the general increase in scientific literature?

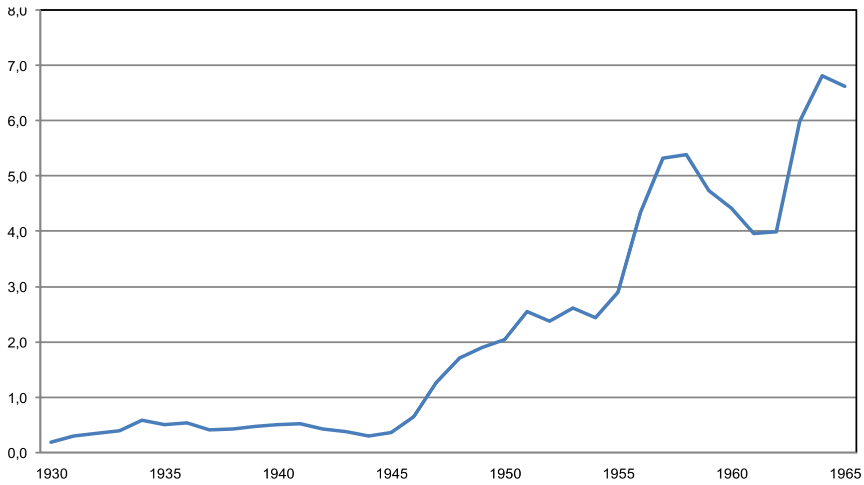
This question can be answered by considering the general increase in papers in the Chemical Abstracts (Graph. 3). The graph is interesting in itself, as it shows the almost exponential increase in scientific literature over the Cold War period. However, its utility is that it can be used as a reference to calculate and represent the proportion of papers with reference to isotopes in relation to the total number of articles (Graph. 4).

Graph. 3. Published articles indexed in Chemical Abstracts, 1930-1965 [35]



35. The number of articles abstracted in Chemical Abstracts has been taken from the CAS Statistical Summary, 1907-2007, available at the Chemical Abstracts website: http://www.cas.org [last accessed Nov 16 2008].

Graph. 4. Percentage of articles dealing with isotope science in relation to all articles indexed in Chemical Abstracts 1930-1965



The image confirms the rise of isotope sciences after World War II. Additionally, it provides a telling indication of the magnitude of this growth in relation to all scientific disciplines and shows a clear difference from the state of isotope sciences before the war. In the 1930s, the number of articles was about 0.5% of the total. In the 1950s and 1960s,at least 7% *of the total number of articles* published referred in some way to isotopes. The growth of isotope sciences in relation to other research areas in this period reinforces the idea that this field developed in accordance with the patterns of large-scale research [36].

This large quantity of publications (thousands of articles per year) makes it difficult to quantify which areas were most affected by the «rise of the isotope» and how this process took place in different countries. Accordingly, my analysis of publication patterns only has taken into account the number of isotope science-related books published between 1946 and 1961. The choice of books is convenient as national adscription is more easily traceable, and can be considered reliable by contrasting the patterns

36. On large scale-research, see Galison, Peter; Hevly, Bruce. Big Science: The Growth of Large-scale Research. Stanford: Stanford University Press; 1992.

of growth in this kind of publication with those of articles, which are very similar [37].

My study has taken into account the books on isotopes published between 1946 and 1961. According to the Chemical Abstracts database, in this period 230 books were abstracted on subjects related to isotopes. I have classified these books according to two parameters: nationality and subject. To avoid confusion, I used broad categories to determine these two parameters and, in some cases, divided the contribution of the book into different topics or disciplines. The results of this analysis appear in Table 3 and Figure 5.

Table 3. Books published on isotopes, by discipline (per cent)

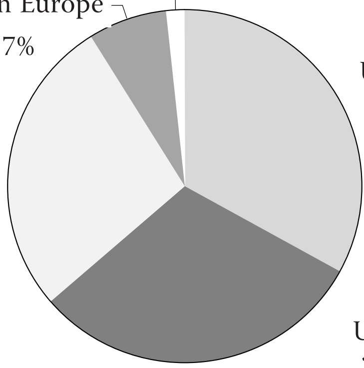
	1946-51	*1952-56*	*1957-61*	*Total 1946-61*
Production and handling	30	15	25	23
Industrial applications	3	10	25	19
Generic	20	18	14	16
Biology	27	17	11	15
Chemistry	3	2	18	15
Medicine	17	24	5	10
Archaeology, Geology, Cosmology	0	4	1	2
Total of books	30	57	143	230

Source: Chemical Abstracts Platabase

Table 3 shows that, despite the importance of the medical isotope market, most of the books were devoted to industrial applications, and that these applications were increasingly prominent in the general literature. At the same time, generic books and technical manuals proliferated, which is possibly an indication of the interest in rapidly developing a community of experts and to recycle scientists to be introduced to this field. In relation to the national origin of these books (reflected in Graph. 5), it is important to acknowledge that I have only found books produced in Europe and the

37. The most serious objection in considering books to be a good indicator would be related to differences in publishing patterns in different nations. Accordingly, I suggest taking these results as rough estimates.

Graph. 5. Books published on isotopes, according to Chemical Abstracts, by country, 1946-51



United States, which is possibly because of bias in the database. In any case, the most interesting feature is the importance of scientific productions by Soviet researchers. In the last section, we have seen that Soviet and Eastern European scientists in general suffered a veto on isotope training programmes. However, a number of experts were trained in the Soviet bloc to help its nations' nuclear establishments to lead nuclear science and technology in the 1960s. This phenomena draws attention to an important gap in our knowledge of the history of isotope sciences: the existence of significant isotope distribution and training programmes, as well as a parallel isotope market, behind the Iron Curtain.

5. Conclusion

Industrial uses of isotopes were as important as uses in biomedical sciences, providing justification for the isotope programmes in several western countries, and, more generally, for national nuclear projects. In 1957, AEC commissioner Willard Libby presented a report to the AEC on the uses of isotopes, estimating annual savings of $500 million derived from their deployment in industry. According to the report, the distribution of isotopes would have paid for the entire US AEC programme by 1960. In the late 1950s, similar reports were produced by other countries' isotope divisions. In the United Kingdom, the Isotope Division estimated savings of $50 million. In the 1957 report, it was stressed that their work had been highly productive:

> «We do not make such extravagant claims for our services to industry, but many of the applications which are saving so much in America were developed in our laboratories. Given adequate staff, we can return the cost of their maintenance many times over to the taxpayer in the shape of improved production and improved living conditions. What is more, the taxpayer will not even be required to pay, for in the long run the increased staff can be self-supporting, as it has been in the past» [38].

The 1963 report by the Department de Radioelements at the French CEA displays similar arguments, with only a slightly cautious estimation of savings. Radioisotopes were widely used in many economic sectors, such as energy production, metallurgy, foundry, chemical industry, and the paper and rubber industries. According to the French report, isotope techniques were still at a «pre-industrial» and «experimental» stage, and needed to be extended to industrial settings in order to increase automatisation and the quality of products [39].

We can explain all of these reports from a dual perspective. From an ordinary perspective, they reflect the extension of isotope techniques to industry, which was achieved through the involvement of the national nuclear establishments in the promotion of isotope-based industrial research. This is congruent with the existence of an important community of users, reflected in the sales statistics, the training of students at isotope schools and the contents of contemporary scientific literature. In the 1960s, isotopes appeared not only to be promising, but also to be almost consolidated industrial elements, leading to automatised atomic factories, to a new technological era based on the atom, which would have superseded the previous ages of wood, coal and oil.

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38. Putman, J. L. Isotope Division Status Report. August 1957. UK National Archives. File AB 6/657.
39. Département de Radioéléments, CEA. Enquête sur l'utilisation industrielle des radioéléments en France. May, 10, 1963. CEA Archives. File F8/04_04, 76-973 (HC). REA Boite 1/2.

However, at the same time that nuclear programmes had turned to power generation, isotopes were becoming less prominent in the whole enterprise. It is in this sense that we understand reports on industrial uses to have been more of an attempt to defend isotope divisions within nuclear establishments. They were now turning to more commercially-oriented projects and abandoning the isotope programmes that, until then, had constituted their public «shop window». ∎