RADIATION PROCESSING INDUSTRY

The Early Years

iia

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List of Abbreviations

AAMI	Association for the Advancement of Medical Instrumentation
AECL	Atomic Energy of Canada Ltd.
CEA	Commissariat à l'Energie Atomique (France)
CPD	Commercial Products Division
FAO	Food and Agricultural Organisation of the United Nations
FDA	Food and Drug Administration (USA)
ICGFI	International Consultative Group on Food Irradiation
ICT	Insulated Core Transformer
IFFIT	International Facility for Food Irradiation Technology
IFIP	International Project in the Field of Food Irradiation
IAEA	International Atomic Energy Agency
iia	International Irradiation Association
IMRP	International Meeting on Radiation Processing
ISO	International Organisation for Standardisation
MCi	Million curies
MIT	Massachusetts Institute of Technology
UK AEA	United Kingdom Atomic Energy Authority
WHO	World Health Organisation

November 2022

International Irradiation Association

Cover Photo: John Masefield (right) at the control console of the potato irradiator

Photo Credit: Getty Images - BET:516571460

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In Tribute to John Masefield

This document is published by the International Irradiation Association on the occasion of the 20th International Meeting on Radiation Processing and in tribute to John Masefield, a pioneer of the radiation processing industry who chaired the Association during the first two decades of its existence.

It seemed opportune to try to narrate in a single document the developments that took place in a period going approximately from 1950 to 1980 because this is when radiation processing became more than a research theme and transformed into an industry. It did not happen all in one place or over a short period of time. Rather, during these booming years, there was a flurry of ideas to domesticate a new form of energy for peaceful purposes. These ideas and attempts to implement them frequently appeared simultaneously in different countries.

Yves Henon is the principal author of this document. Yves joined the irradiation community in 1980, at the end of the period being covered, first working in a research centre, then managing irradiation plants before becoming a consultant for the IAEA and the iia. He is therefore well placed to reflect on the evolution of our industry.

The focus on North America and Europe is perhaps exaggerated. We are aware that important developments have also occurred elsewhere, for example in Japan. The time and resources available to write this document combined with the difficulty in finding or accessing certain historical sources of information have imposed limits to this work. Perhaps it will be taken up, improved, and expanded by others. In the meantime, it is hoped that readers will find these stories useful.

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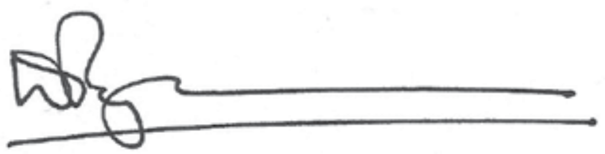


Paul Wynne
Chairman, International Irradiation Association

Introduction

Though largely unknown to most people, the radiation processing industry is now a well-established and global industry. Its history can arbitrarily be divided into two periods. The first one spans from the early 1950s to the late 1970s. It is an age of pioneers. Most of them were engineers who became businessmen, and they would frequently exchange with scientists during meetings and conferences. Passionate advocates of their technology and its applications, to the point of sometimes lacking objectivity, they had to overcome scepticism and constantly repeat that no, irradiated products are not radioactive. They spoke in megarads, a now ancient dose unit. Even the expression 'radiation processing' was rarely used in discussions, books and articles. The 1971 Yearbook on Science and Technology (McGraw Hill) speaks of 'process radiation'. By its title, the First International Meeting on Radiation Processing in 1976 greatly contributed to consecrating and propagating the use of this name which adequately describes the process.

The second period began in the 1980s which marked the beginnings of a new era with rapid international expansion, this was followed in the early 2000s, by numerous mergers and acquisitions from which several global players emerged. We now speak in kilograys and validate rather than commission.

The principal actors and witnesses of the earlier period have now passed away. I was fortunate to have met many of them while they were still active. When the project of writing this brief history of the early years of the radiation processing industry was formed in 2021, it was realised that it was already too late to collect the memories and archives of those who built our industry. Many of the documents covering the period from 1950 to 1970 have become difficult to access.

Imperfect as it is, this short history is intended as a testimony of and a tribute to the work that our predecessors had to accomplish to bridge the gap between science and industry.

Yves Hénon
Director, International Irradiation Association

Fathers of the Radiation Processing Industry

Picking people and naming them Fathers of the Radiation Processing Industry could be tainted with arbitrariness. But there is some sort of “Who’s Who” in the field of radiation processing, which is the list of IMRP Laureates (Annex 1). All but one of those appearing hereafter (Roy Errington who retired in 1974) received the IMRP Laureate Award, which is bestowed to those whose contributions have significantly advanced the field of radiation processing since the second IMRP in 1978.

They must be remembered: they left all who are now active in the radiation processing industry the duty to administer their legacy.

A tribute to

John Masefield (1933-2022)

IMRP Laureate 1984

John Masefield, Chairman of the International Irradiation Association for fifteen years, was passionate about this work and used all his skills and charisma to advance the applications of irradiation for nearly 60 years. John also served on the Board of Directors of the Association for the Advancement of Medical Instrumentation (AAMI) and was Co-Chairman of the International Standards Committee (ISO) that ultimately developed the worldwide standards for the radiation sterilisation of medical products (accepted as ISO 11137). In 2003, he received the Kilmer Memorial Award for International Leadership in Advancing the Science and Practice of Radiation Sterilisation.

Born on July 17, 1933, in Codsall, England, John was educated in engineering and physics in the UK before moving to Atomic Energy of Canada Ltd (AECL) in the 1950s [1]. He joined the Commercial Products Department (CPD) of Atomic Energy of Canada in 1959. There he was part of the team who designed and built the Ethicon gamma irradiator but also the Mobile Demonstration Irradiator that went into action in October 1961, to prove to the Canadian potato industry that irradiation was a reliable, safe, and simple tool able to prevent potatoes from sprouting [2]. Soon after, John left AECL to create the first commercial food irradiator.

He founded Irradiated Foods of Canada Ltd., a name changed to Newfield Products in 1964. The large irradiator leased to him by CPD started operation around September 1965 in Mont-Saint-Hilaire, Québec. John Masefield was the firm's technical vice-president. Unfortunately, the venture soon turned into a disaster. Newfield Products lost 350,000 Canadian dollars in its first year of operation. The loss was partly due to the worst rains in 50 years that ruined the potato crop and a lost gamble on the future potato market. Newfield Products went into receivership in November 1966.

He then met Herbert Lank, Chairman of Du Pont Canada who advised him to spend a few years figuring out what went wrong and to develop a revised commercial irradiation business plan that would work and, in the meanwhile, teach a course in irradiation. John did so over several years at Montreal's McGill University while doing consultancy on irradiation through a company named Masefield Enterprises. Then various medical manufacturers started switching from ethylene oxide sterilisation to irradiation. John thought that the time was ripe to establish a chain of irradiation centres in the US to which manufacturers could ship unsterilised products for treatment en route to market. Having convinced a few investors, in 1972 he created Isomedix [3]. The first irradiation centre in Parsipanny, NJ, was to be followed by many others in Chicago, Spartanburg (SC), Columbus (MS), Puerto Rico, Toronto, etc. Under John's leadership for 25 years, Isomedix became one of the largest international providers of contract irradiation services and was acquired by STERIS for 142 million USD in 1997. John continued to share his knowledge and help grow STERIS's industrial sterilisation offering by serving as an executive advisor to the company for the next 25 years. When the International Irradiation Association was formed in 2004, he appeared as its natural leader and served as Chairman until his late eighties, never missing a Board meeting. He remained active promoting modern approaches to sterilisation.

Roy Errington (1915-1996)

Born in 1915, to a farming family near Goderich in Ontario, he studied at the University of Toronto [4]. Just before earning a PhD in physics, he was enticed to join Research Enterprises, a Toronto-based wartime manufacturing company. In 1946, Errington was hired by Eldorado Mining and Refining Ltd., initially to sell off a stock of radium, a byproduct of uranium accumulated during the Second World War when Canada was the chief supplier of uranium for the allies. Radium was then injected into cancer tumours to kill them.

When other radioisotopes including cobalt-60 became available in the late 1950s, as head of the Eldorado's Commercial Products Division (CPD), Errington was the driving force behind the development of teletherapy machines, Gammacells and industrial irradiators for food and medical products. He strongly believed that it was important to 'use machines to help sell isotopes and use isotopes to help sell machines'. This certainly proved true with industrial irradiation. In 1963, Errington was made an AECL vice-president [2].

Errington's hands-on ways, his entrepreneurial spirit - within a government owned corporation - and his ability to take risks on unproven products, largely contributed to what Nordion is today. Under Errington, sales at Nordion soared from 230,000 CAD in 1946 to 11 million CAD in 1974, the year he retired. Staff grew from 3 people to 570.

He was treated with the cancer treatment equipment he helped design. At his request, he was given double the doses of radiation that anyone had received up to that point at the Ottawa Civic Hospital. He was told it was enough radiation to kill both the cancer and him as well. He lived out his final years virtually cancer-free in a retirement community in Picton, Ontario. Errington died in 1996 at the age of 81, just a month before being guest of honour at Nordion's 50th anniversary celebration.

Arthur Charlesby (1915-1996)

IMRP Laureate 1980

Dr. Arthur Charlesby can be considered as the father of radiation chemistry. He discovered electron beam crosslinking of polyethylene in 1940 while working at the Royal Academy in London. He was founder and editor-in- chief editor-in-chief of the Journal of Radiation Physics and Chemistry.

Arthur Charlesby was born in London in 1915 [5]. A physicist by training, he was endowed with an acute intellect reinforced by a remarkable practical and commercial flair. These talents bore fruit in later life in an astonishing number of original papers and patents largely concerned with the effect of high energy radiation on polymeric materials.

Charlesby was educated in London and Antwerp and graduated from the Imperial College of Science in London. His early professional career was interrupted by the Second World War, in which he served in the Royal Air Force in the vital field of operational analysis. This work involved collaboration with the United States Air Force on the effectiveness of Allied bombing.

Immediately after the war, Charlesby became responsible for the planning of air traffic in post-war Europe and was involved as an adviser during the Berlin airlift of 1948-49. He then joined the Atomic Energy Research Establishment (AERE) at Harwell working on the effects of radiation on materials. After a period with Tube Investments (TI), heading a small research laboratory at Hinxton Hall, Cambridge, he moved in 1957 to the Royal Military College of Science at Shrivenham as Professor of Physics and Head of Department.

This inaugurated a particularly fertile period in original work when Charlesby's enthusiasm for fundamental research produced a plethora of scientific papers devoted to the effects of radiation on polymers. His significant contribution to this field lay in the discovery that a flexible polymer such as polyethylene could be cross-linked and rendered rigid by exposure to high-energy radiation. The benefits also include the resulting insolubility and non-melting at temperatures higher than fusion of the crystalline phase.

Many commercial applications would ensue with an extensive range of patents world-wide. While it is certainly true to acknowledge the strong commercial thrust of these radiation studies, till the end of his life, Charlesby remained keenly interested in problems of theoretical physics, notably in relativity theory [6].

Dr. Charlesby died in 1996 at the age of 81 in Swindon, Wiltshire.

Charles Artandi (1917-1980)

IMRP Laureate 1978

In 1978 Charles Artandi was named the "Father of Irradiation Sterilisation." The Ethicon irradiation plant which he established in New Jersey by 1960 became the Mecca for people with an interest in radiation sterilisation from all over the world.

Born in Hungary where he achieved his PhD in the Royal Hungarian University of Budapest, Charles Artandi first joined Johnson & Johnson in Australia, prior to his transfer to its Ethicon subsidiary in 1953 [7]. He was assigned the task of developing reliable sterilisation techniques. Having decided to focus on irradiation, Charles and his team produced foundation work on the effects of radiation on one hundred different types of microorganisms, suture materials, and a great variety of packaging materials. The value of 25 kGy as a minimum sterilising dose originates from a study that he and Walton Van Winkle performed in 1959 [8].

In 1976, Artandi was with C.W. Bruch (US FDA) behind the creation of a North American Working Group, under the auspices of the Association for the Advancement of Medical Instrumentation (AAMI) to develop guidelines for controlling the sterilisation of medical devices by radiation. This included the development of satisfactory methods for determining the approximate dose of radiation required to sterilise devices.

Vice President of Research and Development of Ethicon, Inc., Charles Artandi was awarded the Johnson Medal for Research and Development in 1978 —the highest honour the company offers—for his leadership in the development of irradiation technology. In the same year he received the American Nuclear Society's Radiation Industry Award for his pioneering achievements. He received posthumously the Atomic Energy of Canada Pioneer Award for his achievements in the field of dosimetry, radiation sterilisation, standards and methods.

Charles Artandi died during the preparation of the Second Kilmer Conference, held in Washington DC in 1980. His colleagues on the organising committee wrote in the preamble of the proceedings: There appears from time to time an individual whose particular gifts enable him to exercise a profound and beneficent influence on his colleagues. Charles Artandi was such a man. During his long career he became a recognized international authority on industrial sterilisation and occupied many positions where his understanding and willingness to help enabled him to contribute much of value [7].

Paul Cooke *(1924-2020)*

IMRP Laureate 1978

Paul Cook was born in Ridgewood, New Jersey, in 1924. He developed an interest in chemistry at a young age, advancing from a basement laboratory in his parents' home to studying chemical engineering at MIT. In 1943, he put his education on hold to enlist in the army. In the Army Specialised Training Program, he studied mechanical engineering for two terms at Stanford University. As a lieutenant he joined the famed 10th Mountain Division serving in combat in Italy toward the end of the Second World War. Upon completion of his military service, he returned to MIT, completing his degree in 1947. In 1948 he joined SRI International, an independent, not-for-profit research centre serving government and industry [10].

In 1957, starting from a tiny building in Redwood City, Paul Cook founded Raytherm Wire and Cable to take commercial advantage of the crosslinking effect of electron beam on polyethylene for wire and cable insulation. Cook mortgaged his house to rent the very first high-energy electron accelerator produced by General Electric, which was delivered in March 1957 [11]. Later that year, he formed Rayclad Tubes to produce heat shrinkable tubing. Both companies were consolidated into the Raychem Corporation in 1960 and are now part of Tyco Electronics.

Paul and his associates James B. Meikle, and Richard W. Muchmore helped move radiation chemistry from an almost purely experimental niche in research labs into viable applications in industrial processing . Among Raychem's first products were a flame retardant irradiated polyethylene insulated wire and heat shrink flame retardant polyethylene tubing. Raychem's early days were not easy. Soon after processes for commercial production had been scaled up, the tube of the accelerator failed. Without radiation capacity for 11 weeks, Raychem nearly went bankrupt by the time a new tube was finally installed and working.

With offices in more than 40 countries and thousands of employees, Paul served as CEO of this Fortune 500 company until 1990. Raychem was acquired by Tyco International in 1999. At the time of the sale the company had reached sales exceeding 2 billion USD and was operating in over 60 countries. Inspiring a new generation of innovators through his leadership, Paul received many awards in his lifetime. In 1988, President Ronald Reagan presented Paul with the National Medal of Technology for creating a worldwide chemically based industry. He also received the Winthrop-Sears Medal from the Chemical Industry Association and he was named to the San Francisco Bay area business Hall of Fame in 1999. In this spirit of giving back, Paul was very active in his alma mater MIT, serving as chair of the chemical department and becoming a member of the MIT corporation. He eventually returned to SRI as a Director and served as Chairman from 1993 to 1998. Paul Cook loved new technologies, innovators and doers. After retiring from Raychem he was involved in many startups and new ventures. Until his death in December 2020, he remained as chairman of his latest venture, Vox Frontera Inc., a voice recognition company.

Marsh Cleland (1926-2019)

IMRP Laureate 1992

Marshall R. Cleland was born in Vermillion, South Dakota on February 9, 1926. The pursuit of his baccalaureate was interrupted by service in the Army Air Corps during World War II [12]. He obtained his B.A. in Physics from the University of South Dakota and went on to earn his doctorate in Nuclear Physics at Washington University in St. Louis, Missouri, in 1951.

Following a year as a physicist at the National Bureau of Standards then in Washington, DC, Marsh devoted his efforts to developing high power accelerators. This led to his co-founding of Radiation Dynamics, Inc. in Westbury, New York in 1958, of which he was first vice president and then chairman. He developed and commercialised his innovative accelerator, the Dynamitron™. Hundreds of these high-power accelerators have been installed across the world, mostly for the manufacture of wires and cables, heat shrinkable products, tire components and other applications. He spent the last years of his career with IBA Industrial, the Belgian company who acquired RDI in 1999.

Marsh Cleland was awarded eighteen US patents and corresponding foreign issuances, including the basic patent on his accelerator design. He published more than 200 papers and chaired numerous sessions at radiation and accelerator conferences. He also was a member of the American Nuclear Society, the American Physical Society, the New York Academy of Sciences, ASTM International and the Council on Ionising Radiation Measurements and Standards (CIRMS), of which he was a co-founder and its first President.

At the eighth International Meeting on Radiation Processing held in Beijing in 1992, Marsh was named an IMRP laureate. In 2004, he was named a Fellow of the American Physical Society. In 2006, ASTM International conferred the Peter D. Hedgecock Award on Marsh for his sustained and exceptional contributions to the development and use of nuclear-related standards. In 2009, Marsh was awarded the CIRMS Caswell Award for Distinguished Achievements in the Field of Ionising Radiation Measurements and Standards. The Rad Journal honoured Dr. Cleland with its Gunderson Award in 2011 for his lifetime contributions to Radiation Safety and Technology.

Pierre Vidal *(1910-2002)*

IMRP Laureate 1994

Pierre Vidal devoted a major part of his long life to the irradiation industry. He was the first entrepreneur to offer contract irradiation services on a commercial basis and the founder of the first irradiation industry trade organisation.

Born in the region of Lyon and a great wine connoisseur, Pierre Vidal started his professional activity after the Second World War as manager of Entrepôts Frigorifiques Lyonnais (EFL) owned by the Ministry of Agriculture. It was a large complex combining frozen storage, fast-freezing capacity, packing stations, and a disinfestation station for fruit and vegetables. After a stay in the United States, Pierre Vidal was convinced that food irradiation was about to revolutionise food preservation.

In 1956 he founded the Centre Lyonnais des Applications Atomiques (CLAA) near Lyon, the first private gamma irradiation company in the world, but he did not have an irradiator yet. The French authorities delivered the licence in 1958 [13]. In 1961, the CLAA became Conservatome (the atom that keeps) and the first irradiation unit started. The cobalt-60 had been supplied by the French Atomic Energy Commission (CEA) who was a shareholder.

To prove the benefits and the feasibility of food irradiation, Pierre Vidal is also at the origin of IRMA, a mobile irradiator containing 175,000 Ci of cesium-137 built in 1963.

On the site of the first irradiator in Dagneux, near Lyon, two more larger and improved units were built in 1962 and 1972. These facilities were the seeds of the French Groupe Ionisos founded in 1993 and now present in several European countries. Over the years, medical sterilisation and cross-linking of plastics became the core business of Conservatome, but Pierre never stopped pleading the cause of food irradiation and never lost faith in the future of this beneficial application.

Like many pioneers in a new industrial activity, Pierre had to tackle a myriad of problems, often fighting against more regulatory requirements that he found unnecessary. This convinced him that the growing irradiation industry needed to be organised to defend its interests. In 1970, Pierre founded the "Association Internationale d'Irradiation Industrielle" (AIII), of which he remained Chairman until he retired in 1998. At first, members were mostly European irradiation facilities but later the AIII attracted members from all over the world. To ensure that the interests of the irradiation industry would be taken into consideration, Pierre Vidal participated in many meetings and irradiation-related activities. He was a member of several different standardisation committees and used every opportunity to support the harmonisation of standards and regulations [14].

The International Irradiation Association was born from AIII.

Sam Nablo *(1930 -2018)*

IMRP Laureate 1989

An inventor and an entrepreneur, Samuel Nablo was born in Dunnville, Ontario, and attended McMaster University in Hamilton, Ontario, earning his B.Sc., M.Sc., and Ph.D. degrees in Physics. During this time, he met his wife Ruth with whom he would spend 62 years [15].

Sam was a principal in the founding of two high technology companies: MedPak Inc. and Electron Processing Systems, Inc. In 1972, Sam was the co-founder of Energy Sciences Inc., where he helped develop a family of electron processors for industrial use.

Energy Sciences Inc. pioneered the low voltage EB market. ESI received the first U.S. patent for the Electrocurtain Lab Unit. Progressively, suppliers developed new EB compatible coatings and inks. In 1985, ESI introduced the first industrial in-line EB steriliser.

Today, Energy Sciences Inc. (ESI) is the world leader in low energy (up to 300kV) Electron Beam (EB) systems used among others in flexible packaging and folding carton packaging to cure inks, coatings and laminating adhesives. The success of the multicolour lithographic printing of web using single station electron curing opened a large market. With his inquisitive mind and enthusiastic spirit, Sam made fast friends. He died in 2018 at the age of 87.

The recent Team Nablo project, named in his memory and operated by Pacific Northwest National Laboratories (PNNL), explores material compatibility for radiation sterilisation using the three types of ionising radiation.

Early Production of Cobalt-60

In 1953 President Eisenhower gave a major boost to the development of research and applications of radioisotopes by launching the Atoms for Peace initiative. During the decade that followed the Second World War, nuclear research organisations in the USA, Canada, UK, France, Denmark, and USSR developed various types of small-scale irradiators, most often using spent fuel as a source of gamma rays. It rapidly appeared that cobalt-60 would be the radioisotope of choice to produce gamma radiation. Caesium-137 was to be used in hospital and laboratory irradiators only. Various programs currently aim at replacing them by non radioisotopic sources. The use of cesium-137 in industrial irradiators has been very limited and completely ceased after a source leak that occurred in Decatur, Georgia in 1988 [16].

Cobalt-60 was first offered for sale in 1949 by Eldorado, a business established as a gold mining company by brothers Charles and Gilbert Labine in 1926. In the 1930s the company mined radium and then uranium that would become critical during the Second World War. The company was nationalised into a Crown corporation in 1943 [2].

A collaboration between British and Canadian nuclear scientists led to the establishment of the National Research Experimental, or NRX under the National Research Council (NRC). Located in Chalk River (Ontario, Canada), the NRX was the most powerful research reactor of its time. One of its characteristics was the high number of free neutrons that it generated. Cobalt-60 was one of many isotopes that NRX could produce. Nuclear scientists were predicting immediate practical applications in medicine and industry. As the only marketer of radioactive products in Canada, Eldorado appeared as the natural vehicle to sell the isotopes produced in NRX. In 1949 Eldorado got from NRC exclusive rights to distribute cobalt-60 from Chalk River to commercial and industry users. The agreement was later extended to other users and by 1951 all orders for isotopes would go through Eldorado. The person in charge of sales, Roy Errington, decided that the company needed a catalogue for the new line of products and the department became Eldorado's Commercial Products Division (CPD). Errington hired salesmen with a scientific or engineering background.

In 1952, the government of Canada created Atomic Energy of Canada Limited (AECL) to promote the peaceful use of nuclear energy, take over the Chalk River operation from the NRC, and build a second reactor on the same site. That same year AECL took over Eldorado's CPD.

The radium-bombs in use for teletherapy since the 1930s had to be very close to the body surface and the beta radiation would dose skin and surrounding healthy tissue. To produce higher energies, various electric machines were installed but they were expensive, bulky and difficult to maintain and operate. Cobalt-60 appeared as a better alternative. In 1947, Mayneord and Cipriani [17] had determined the energies of the two gamma photons emitted by cobalt-60. These and its half-life made cobalt-60 a very suitable candidate for use in radiotherapy. A stronger, cleaner, and simpler teletherapy source than radium, cobalt-60 was also much cheaper. In mid-1951 the first Eldorado A

Beam-Therapy Unit (BTU) loaded with one thousand curies of cobalt-60 was ready and installed at the Victoria Hospital in London (Ontario). Many units were sold since cobalt-60 teletherapy was revolutionising radiation oncology and naturally competition appeared, often using Canadian cobalt-60 sold by CPD.

After the new Chalk River reactor NRU started operating, the cobalt-60 supply could better face the market growth. CPD had humble beginnings; the main offices were in the basement of a building and extra office space had to be leased nearby. The source loading for the teletherapy machines were taking place in two rented garages isolated from any inhabited structure.

In July 1947, the new reactor NRX achieved criticality and more cobalt-60 became available, but like for the NRU, serious fuel channel cooling accidents temporarily disrupted supply. These accidents created early challenges to the fledgling program's credibility but with them came hard but important nuclear safety lessons [18].

Errington's idea to 'package' cobalt-60 in devices went on with the Gammacell, a self-shielded irradiator that for decades would become a standard equipment of laboratories and hospitals that needed a small gamma irradiation capacity. The prototype of the Gammacell-220 was presented at the Atom Fair in New York in 1957. The salesmen amused spectators by showing that the colour of drinking glasses and eyeglasses could be changed. This was another device having the virtue of requiring replenishments but not as much cobalt-60 as large irradiators that would treat food or sterilise medical devices on a commercial scale. And indeed, the output from the NRX and the NRU would not be enough to meet demand for industrial irradiators, even if they used Low Specific Activity (LSA) cobalt-60 as opposed to High Specific Activity (HSA) in teletherapy units. The first large irradiator designed and built in 1964 by CPD for Ethicon Inc. in Sommerville, New Jersey would require 750,000 curies of cobalt-60. The mother company, Johnson & Johnson would soon want irradiators for their other subsidiaries. In 1967, the German medical manufacturer Willy Rusch near Stuttgart ordered a 1.5 MCi irradiator, the biggest at the time.

It happens that Canada had chosen to develop a heavy water moderated reactor which became known as CANDU (standing for Canada Deuterium Uranium) to produce electricity. As the result of a collaboration between AECL and the Hydro-Electric Power Commission of Ontario, the predecessor to Ontario Hydro (which was later reorganised into five components, including the still-existing Ontario Power Generation), the Nuclear Power Demonstration (NPD) reactor built by Canadian General Electric (CGE) commenced operation in 1962, supplying 20 MW of electricity to the Hydro system [19]. NPD was followed by the ten-fold larger prototype, Douglas Point, which commenced operation in 1967. Located at what later was to become Ontario Hydro's Bruce Nuclear Power Development site on Lake Huron, Douglas Point, together with NPD, established the technological base necessary for the larger commercial CANDU units to follow in the 1970s and 1980s at Pickering, Bruce and Darlington stations.

CPD asked Hydro to consider producing cobalt-60 in their power reactors by putting cobalt-59 into the control rods. Hydro agreed after having determined that this would not alter the performance of the reactors. The shape of the LSA sources used for industrial irradiation would differ from HSA sources and they would have to be removed during regular maintenance shutdowns every 18 to 36 months. A mutually beneficial agreement was signed by which CPD would establish its place as leading supplier of cobalt-60 and Hydro would get extra revenue from a by-product of CANDU operation. However, Hydro demanded that any cobalt-60 they were asked to produce would be paid. At Chalk River, CPD would not have to pay for any cobalt-60 that it did not use. Forecasting demand years ahead on a new market would become a critical exercise for CPD. AECL and Hydro subsequently developed the capability for producing large quantities of Cobalt-60 in several of Hydro's CANDU units.

AECL reorganised its operation in 1978 and CPD became the Radiation Chemical Company (RCC). In 1988, the company reincarnated as the privatised Nordion International Inc.

In 1960, CPD celebrated the shipping of its one millionth curie. Around 2010, Nordion passed the one billion curies mark. Canada's current share of the world Cobalt-60 market is estimated at about 80%.

As applications of irradiation developed and demand increased, cobalt-60 production technology was developed in Russia and India. Cobalt-60 was first produced by MAYAK p.a. in Russia in 1963 and was later expanded into the Leningrad Nuclear Power Plants. Indian production of Cobalt-60 started in the mid-1970's following intense investment and development of the country's nuclear, isotope production and radioactive source production infrastructure and capabilities. In 1985, Argentina started production at the Embalse reactor.

The First Commercial Gamma Irradiators

The first in-house gamma irradiators

The world's first commercial gamma irradiation plant was constructed at Dandenong, Victoria, for the company Gamma Sterilisation Pty Ltd. in 1959. It had an initial load of 150,000 curies of cobalt-60 and was designed to irradiate goat hair bales exported to the UK parent company Westminster Carpets to manufacture carpets. There was a concern that the deadly bacteria anthrax could be present in the wool, and irradiation was a good safety measure, the same as used many years later for government mail in the United States. The advent of synthetic materials put a stop to the import of goat hair to manufacture carpets and consequently irradiation was no longer needed. The plant continued operating as a general-purpose irradiator, sterilising various medical products and biological tissues on a contract basis until 1976. It was then declared obsolete and dismantled, the cobalt-60 being sold and transferred to the Australian Atomic Energy Commission. It had also suffered from competition. In 1971, an AECL JS6500 radiation plant was installed — also at Dandenong — for Tasman Vaccine Laboratory (Australia) Pty Ltd., a subsidiary of Tasman Vaccine Laboratory (New Zealand) Pty Ltd. These companies were acquired in 1976 by I.C.I. (New Zealand). Contract sterilisation was the main business with a small part of the capacity being used for the company's own products, mainly dressings. In 1972, Johnson & Johnson (Australia) Pty Ltd. built the third Australian industrial radiation plant in Botany (New South Wales), also an AECL JS6500, to sterilise their own products only [20].

The Ethicon Irradiator

In 1961, Ethicon Inc., of Ralway, New Jersey, a US subsidiary of Johnson & Johnson had decided to acquire a gamma irradiator to sterilise sutures and other single-use medical items. Two potential suppliers were invited to bid: the Canadian AECL CPD and a British firm, HS Marsh Ltd., which had an arrangement with the UK Atomic Energy Agency. The CPD got the deal [2]. The facility was built in Sommerville, New Jersey, in 1964. That same year Johnson & Johnson's Ethicon Division also constructed gamma irradiators in San Angelo, Texas and Peterborough, Ontario.

Johnson & Johnson built two more in-house irradiators in Texas (San Angelo) and in England (Slough) before 1965.

An irradiator dedicated to the production of wood-plastic flooring was also built in the United States at about the same time.

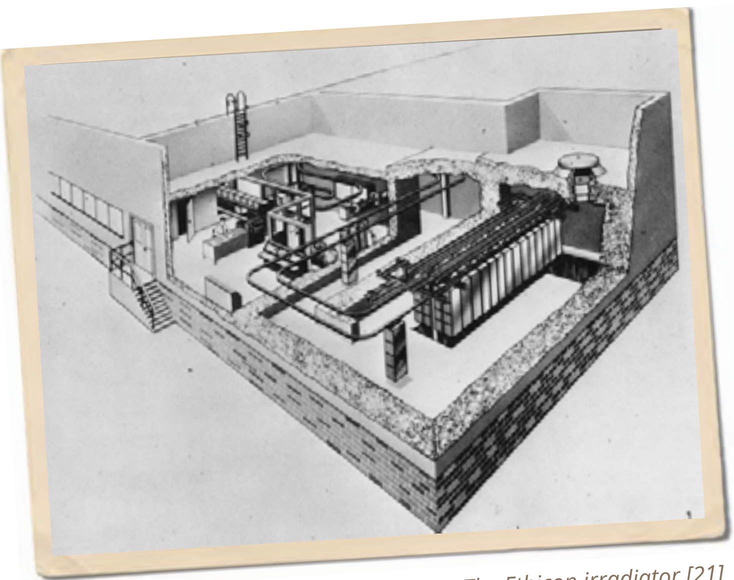


Figure: The Ethicon irradiator [21]

The first multipurpose gamma irradiators

In early 1960, the first semi-industrial gamma irradiator built and operated by a private company specifically for the purpose of offering commercial irradiation services to third parties started in Dagneux, near Lyon, France. The owner, Pierre Vidal, believed that preservation of food by irradiation was just around the corner so he named the company Conservatome. He had to fight hard to get the funding (CEA and Michelin had a participation), to get the licence (first powerful radioactive sources outside a military zone or nuclear research centres), and to get cobalt-60, a rare and expensive material in the late 1950s. The first sources came from Oak Ridge (3,000 then 40,000 curies) [22].

That same year 1960, the world's first large gamma irradiator facility was commissioned at the Research Laboratory of the UK Atomic Energy Authority in Wantage. Intended as a pilot plant, the facility consisted of two gamma units, one continuous type, and the other of a batch type. Both would store the cobalt 60 sources in water pools. The total source loading reached half a million curies by 1970.

The continuous plant, known as the Package Irradiation Plant, incorporated automatic conveying of standard packages to the irradiation room. Initially it was able to process 5 to 6 m3 of products per day at 25 kGy.

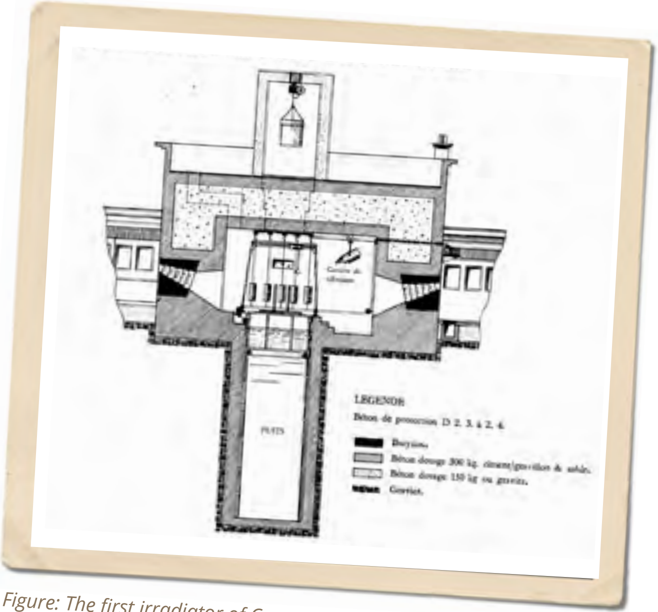
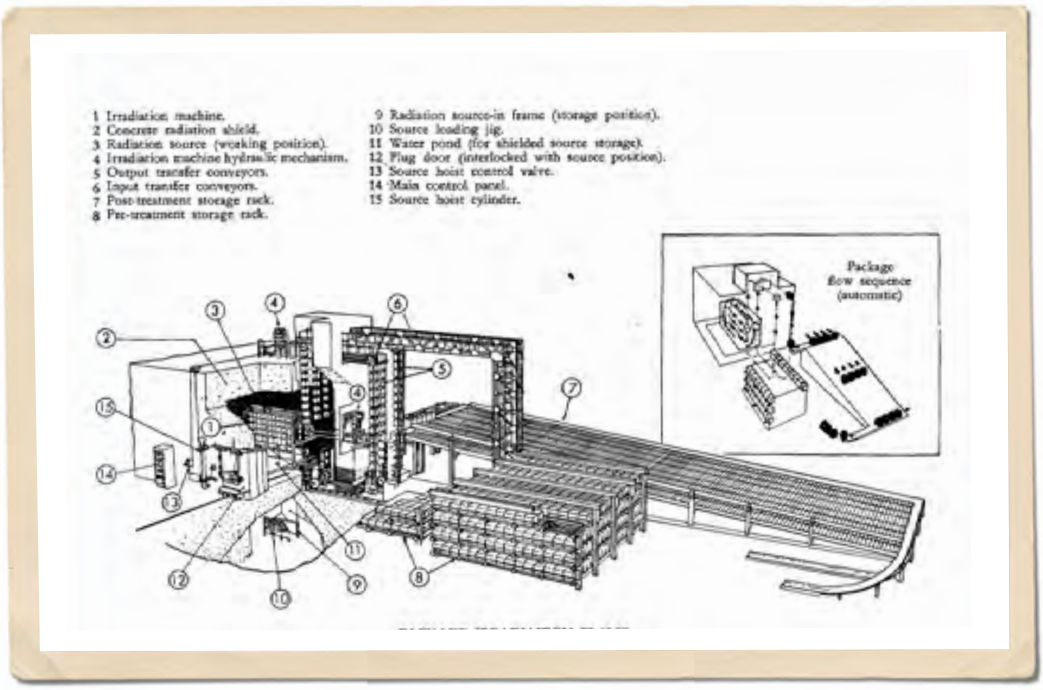


Figure: The first irradiator of Conservatome



Picture: The irradiators hall at Wantage [24]

A wide variety of industrial firms were able to carry out large scale market trials on their products. It was not long before two private companies decided to enter the business of irradiation for third parties. In 1967, Irradiated Products Ltd (IPL) was set up and managed by two ex-scientists from the UK Atomic Energy Authority. The company was owned by London Rubber, a manufacturer of latex gloves. The UKAEA Wantage facilities were leased to IPL from 1970 to 1972 before being demolished in 1973. In 1969, H.S. Marsh Ltd designed and constructed a plant for Gamma Radiation Services Ltd (GRS). IPL and GRS merged to form Isotron in 1983. Two years later Isotron became the first irradiation company to be floated on a stock exchange. Isotron acquired Gammaster in 2001 and was acquired by Synergy Health plc in 2007.

By 1970, there were two dozen large gamma irradiators sterilising medical devices and most of them were in Europe.

The First Large Gamma Irradiators

Location	Operator	Designer	Capacity (MCi)	Since
Argentina – Ezeiza	CNEA	CNEA	1	1970
Australia – Dandenong	Gamma Sterilization Pty	AERE Harwell	2	1960
Denmark – Roskilde	Nunc A/S	AECL	1	1969
France - Dagneux	Conservatome D1	CLAA	1	1960
France - Dagneux	Conservatome D2	Conservatome	1	1968
France - Dagneux	Conservatome D3	Conservatome	1	1973
Germany – Hamburg	Ethicon GmbH	Marsh	0.75	1966
Germany – Melsungen	B.Braun Co.	Sulzer Brothers	0.6	1966
Germany - Rommelshausen	Firma Willy Rüsch	AECL	1.5	1968
East Germany – Rossendorf	Zentralinst für Kernforschung	Own design	0.5	1967
Italy - Bologna	ICO SpA	Marsh	0.5	1967
Japan – Tochigi	Japan RI Irradiation Service		0.5	1970
Netherlands – Ede	Gammaster	AECL	1	1970
New Zealand – Upper Hut	Tasman Vaccine Lab.	AECL	1	1966
Sweden – Skärhamn	Radona Irradiation AB	Marsh	1	1968
UK – Wantage	Irradiated Products Ltd (PIP I)	Rubery Owen	0.7	1960
UK – Slough	Johnson's Ethical Plastics	Marsh	0.75	1962
UK – Reading	Gillette Industries Ltd	Marsh	0.75	1964
UK – Wantage	Irradiated Products Ltd (PIP II)	UKAEA	0.7	1965
UK – Reading	Gamma Radiation Services Ltd	Marsh	1	1970
USA – Sommerville, NJ	Ethicon Inc.	AECL		1964
USA - San Angelo, TX	Ethicon Inc.	AECL		1964
USA - North Canaan, CN	Becton Dickinson	AECL	1	1970

Table extracted from Table II in [25]

The First Industrial Accelerators

During the first half of the 20th century there was a lot of interest in accelerators, and various machines were invented for laboratory use. By the 1940s, three acceleration mechanisms had been demonstrated: DC acceleration, resonant acceleration and the betatron mechanism [26]. After the Second World War the challenge was to build machines for industrial use.

The first industrial high current electron accelerator was developed by a protégé of William Coolidge at the General Electric Company (GE), Willem Westendorp [27]. Patented in 1940, it is a resonant transformer system, which increases voltages from 200 to as high as 44,000,000 in a series of low frequency “pushes” from carefully tuned coils [28].

While intended to be a high voltage source for X-rays, the GE resonant transformer was adopted for industrial use, for example at Raychem in 1957 [27].

Robert Van de Graaff (1901-1967) is the American physicist who invented the accelerator named after him, a type of high-voltage electrostatic generator. The device found widespread use in atomic research, medicine, and industry. Van de Graaff had developed his interest in atom physics while attending the lectures of Marie Curie at the Sorbonne in Paris in 1924 [29]. Back in the United States he conceived the idea of a high voltage generator for X-rays and spent years developing it with his colleague John Trump at the Massachusetts Institute of Technology (MIT). In 1946, Van de Graaff and Trump co-founded the High Voltage Engineering Corporation (HVEC) [29]. They designed an insulating core transformer (ICT) accelerator for which a patent was issued in 1965. The machine was improved for industrial use by Roy Emanuelson, an HVEC engineer. For decades now, ICTs in the 300 keV to 2.5 MeV range have been widely used for crosslinking.

John Cockcroft and Ernest Walton were the first to split the atom in Cambridge, UK, in 1932. For that they had designed a generator, or multiplier, which was an electric circuit generating a high DC voltage from a low-voltage AC or pulsing DC input. This machine design remains the basis for many high-current, mid-energy electron accelerators currently used in industry [27].

In 1956, Marshal Cleland at Washington University invented a variation of the Cockcroft-Walton accelerator that he called Dynamitron® in

Picture: Willem Westendorp looking at a roll of Irrathene® one of the very first irradiated polymers [28].

which voltage is induced in semi-circular corona rings attached to each end of the diode rectifier tubes. The accelerator stack is inside a tank of pressurised sulphur hexafluoride gas for insulation [30]. The advantage of this design is that it can produce higher beam currents than the Cockcroft-Walton design, up to hundreds of milliamperes. Having been rejected by HVEC in attempting to licence his technology, Cleland followed the advice of Arthur Holly Compton, then Chancellor of Washington University in St. Louis, and went to the New York City area to obtain venture capital. There, along with a graduate school classmate, Kennard Morganstern (IMRP Laureate 1985), they founded Radiation Dynamics, Incorporated (RDI) in 1958 [31]. More than 200 Dynamitrons® were sold by RDI, now belonging to IBA.

The Swedish physicist Gustaf Ising (1884-1960) proposed the concept of radiofrequency (RF) linear accelerators (Linacs) and the Norwegian physicist Rolf Wideröe (1902-1996) constructed one in the 1920s. The method was resonating particles with a radio frequency electric field to add energy to each traversal of the field. At Stanford University, two brothers, Russell and Sigurd Varian, worked to develop a source of strong microwave signals to improve air navigation and warn of potential Nazi bombing raids. On August 30, 1937, they presented the klystron, a high-frequency amplifier for generating microwaves [32]. This invention made it possible to increase the power levels of Linacs. The two brothers could reach energies of 10 MeV with average beam current of 1 to 2 mA. Linacs are now commonly used for the sterilisation of medical devices.

Sam Nablo developed a low-voltage accelerator (≤300 kV) based on the ideas of an Energy Sciences Incorporated (ESI) engineer, Bertram Quintal, that relies on self-shielding of the accelerator and under-beam conveyance with lead (or steel) to protect the personnel from X-rays emissions.

A technique of using parallel segmented filaments for low-energy accelerators was developed by Sherman Farrell in 1975, which was adopted by RPC Industries, now PCT Engineered Systems [27].

The most recent type of high-energy accelerators is also one of the most original. The Rhodotron, where electrons are accelerated in a flower-shape recirculating pattern was the idea of J. Pottier and his team at the Saclay Nuclear Research Centre of the French Atomic Energy Commission (CEA) near Paris in the 1980s. The CEA did not wish to commercialise the machine. Ion Beam Applications SA (IBA), initially a spin-off of the research centre for cyclotrons of the Catholic University of Louvain (Belgium) obtained an exclusive licence in 1989. There was still considerable work to be done. Yves Jongen (IMRP Laureate 2003) and Michel Abs developed a 10 MeV, 100 kW prototype that successfully completed the beam tests at the end of 1994. Three machines were sold in 1995. [33] These machines may soon open the era of X-rays for industry.

The First In-House Industrial Accelerators

In the 1950s, low-energy or medium-energy electrons were the only option for those who wanted to use irradiation for their products. Cobalt-60 was scarce and expensive. The German company Gewurzmüller acquired a van de Graaf machine for the microbial decontamination of their spices but could not use it for long because of a sudden ban on food irradiation [34].

In 1957, Ethicon in Sommerville, New Jersey, bought a 2 MeV-5 kW microwave linear electron accelerator made by High Voltage Engineering Corporation to sterilise sutures. The limited penetration of the beam and the reliability of the machine being insufficient, the company switched to gamma irradiation in 1960.

With the chemical industry realising the industrial potential of irradiation for polyethylene cross-linking, companies like the General Electric Company, Raychem and Cryovac purchased electron accelerators. As is still the case today, information on the number and characteristics of machines is hard to come by, as this is a sector where secrecy is important to maintain commercial advantage.

The first contract service accelerators

In the autumn of 1960, the Danish Atomic Energy Authority started operating a 10 MeV Linac Model V 77700 from Varian Associates (Palo Alto, California) in their Risø research establishment. The machine produced a stable beam with an average power of 5 kW. The conveyor speed could vary from 0.2 to 600 mm/s. First used for research only, the accelerator started providing sterilisation services to medical device manufacturers in 1961.

The first private company created to offer electron beam processing services was CARIC - SRTI (Société de Recherche et Technique Industrielle) in Corbeville near Paris in 1967 [35] with Pierre Icre as its manager. The facility was equipped with a 6 MeV, 7 kW linac named Circe 10 manufactured by a subsidiary of Thomson, CGR-MeV, whose Director, Theo Sadat (IMRP Laureate 2006), was a staunch advocate of accelerators. After having built another service facility in the Champagne region in the 1980s, CARIC was acquired by Ionisos.

Development of Applications

Enhancement of Polymer Properties

The importance of radiation processing to enhance the properties of polymers is often overlooked, though it is by far the main industrial application of irradiation. If these commercial applications receive little publicity, it is because their development and even their use have mostly taken place in secret due to the economic stakes in a competitive environment.

When nuclear fission reactors provided relatively inexpensive, powerful gamma radiation sources after the Second World War, the creativity of chemists was stimulated. The fact that ionizing radiation brings energy to a system and can modify it without residues was of great interest to the chemical industry. When it became practical to use irradiation outside laboratories, various attempts were made to synthetise chemicals or improve catalysts with the help of irradiation. Fortunately, the idea of turning nuclear reactors into chemical plants where radiation would assist chemical processes did not go too far. Irradiation of abundant bulk material such as natural gas, coal, oil, or rubber did not prove successful [36]. Using irradiation for chain chlorination of molecular compounds was abandoned because it was too difficult. The Brookhaven National Laboratory and the Takasaki Radiation Chemistry Research Laboratory developed a process to induce polymerisation of ethylene at high pressure by gamma radiation but this was not commercially applied [37]. In 1963, the Dow Chemical Company went as far as starting the commercial production of ethyl bromide in Midland, Michigan by inducing the addition of hydrogen bromide to ethylene with a source of 1,800 curies of cobalt-60 in an underground tank. [38].

A related application is the treatment of flue gases, where the energy from radiation is absorbed by nitrogen, oxygen and water to form active chemical species that will oxidise sulphur dioxide and nitrogen oxides, which are toxic gases emitted by coal and oil-fire boilers in power plants. For many years, Prof. Andrzej Chmieliewski (IMRP Laureate 2013) has advocated this application, now categorised as an environmental application of irradiation. The concept to remove sulphur dioxides and nitrogen oxides using electron beams was first suggested and investigated by the joint research of the Japan Atomic Energy Research Institute (JAERI) and the US Ebara Corporation. The first plants were constructed in the 1970s by Ebara, included one for the Nippon Steel Corporation, which successfully treated iron ore sintering exhaust gas using two electron accelerators. A few more installations were built in Germany, China and Poland.

Due to the non-specific nature of many radiation-induced reactions and the relatively high cost of ionizing radiation as an energy source, the applications in industrial chemistry failed for safety, technical or economic reasons. It soon appeared that, as the specific energy requirements for radiation-chemical determines the required absorbed dose, higher molecular weights would be provide more favorable opportunities [39]. Modification of polymers eventually became the main application of irradiation, certainly not as the result of an evidence, but rather from multiple observations, trials and errors.

The design and contruction of nuclear reactors was a main driver to better understanding the effects of irradiation on materials such as polymeric materials given that they could impact the safety, operation and longevity of equipment.

Davidson and Geib reported in 1948 that the molecular weight of natural rubber bombarded in the Oak Ridge atomic pile increased [40]. In 1950, Dole reported that polyethylene crosslinks under irradiation while presenting the M.Sc. thesis of D. G. Rose on the Effect of Radiation on Colloidal and High Polymer Substances at a Symposium of the US Army Chemical Center. The first scientific article on the topic, *Cross-linking of polythene by pile radiation* was published by Charlesby in the Proceedings of the Royal Society in November 1952 (volume 215, issue 1121). It is an extensive study conducted in the UK Atomic Energy Authority atomic pile at Harwell [39].

Irradiation could thus be envisaged as a physical method to produce crosslinking in polyethylene and in other long-chain polymers under accurately controllable conditions, without the incorporation of other chemical compounds and without heat treatment. Commercial applications rapidly followed, using the accelerators available at the time, generating what would become a multi-billion-dollar business.

In January 1957, Paul Cook founded Raytherm Wire and Cable and crosslinked by irradiation the polyethylene for wire and cable insulation. Later that year, he formed Rayclad Tubes to produce polyethylene heat shrinkable tubing. These businesses were consolidated into the Raychem Corporation in 1960, which became part of Tyco Electronics. In 1961, industrial irradiation of wires and cables also started in Japan.

In 1956, Bill Baird from the Cryovac Division of what was to become W. R. Grace - and is now part of Standard Industries - visited Paul Cook to also use radiation crosslinking for producing heat shrinkable materials. The Cryovac® Type L plastic shrink films and bags to protect meats and poultry, was marketed by Grace in 1960. While Raychem has long been acknowledged to have more installed kilowatts of electron beam power than any firm, Cryovac would have more accelerators (ICTs and Dynamitrons) in their manufacturing operations.

The 1960s would see a diversification of new applications to polymers, starting with coatings. Bill Burlant at the Ford Motor Company used electrons of a few hundred keV to cure automotive coatings using cable connected scanned beam accelerator produced by RDI. Daniel Carlick, Technical Director of Sun Chemical, a leading ink manufacturer, developed the use of electron beam in curing printing inks. Substantial businesses have evolved based on providing the raw materials, monomers, and oligomers, used in EB curable inks, coatings and adhesives, and formulated systems [27].

In Japan, manufacturers of radial tires started using electron beam to partially crosslink plies that would be molded and cured into the final tire. The advantage is the capability to better position tire cords and hold them in place in the final molding process. In 1966, P.A. King was the first to crosslink polyethylene oxide to produce hydrogels which would find application in the production of dressings that create a moist healing environment and are painless to change. Hydrogel dressings produced by radiation technology were later developed by Prof. Janusz Rosiak from the Institute of Applied Radiation Chemistry, Lodz University of Technology, Poland.

One of the applications of radiation polymerization was the production of flooring resistant to humidity, wear and abrasion. Red oak impregnated with a methyl metacrylate was the common recipe to produce wood plastics. In 1976, there were 3 gamma facilities producing wood acrylics in the USA: Applied Radiant Energy in Virginia, Radiation Technology in the state of New York, and Arco Chemical in Pensylvania [41]. The development of closed cell polyethylene foams used for padding in cars or to make gym rugs emerged in the 1970s.

If radiation processes and products were developed almost exclusively by private companies, the role of academia in the development of polymers irradiation cannot be understated. If Arthur Charlesby is rightly considered as the founding father of radiation chemistry applied to polymers, several others had a major contribution in the advancement of this science.

Joseph Silverman (1922-2019)

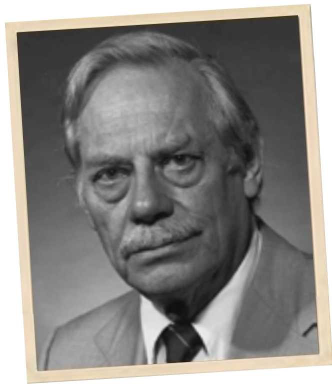
IMRP Laureate 1987

Joseph Silverman was one of the creators of radiation chemistry and the processing of polymers, and one of the most distinguished radiation chemists in the world.

A professor in the Department of Materials Science and Engineering at the University of Maryland, Joseph Silverman had a long and distinguished career. He had earned his Ph.D. in Physical Chemistry from Columbia University in 1951. He served eight years in industry, and a year as an associate professor at Stony Brook University before he was recruited in 1960 to help launch the University of Maryland's nuclear program as part of the Department of Chemical Engineering. An expert in the interaction of ionizing radiation with polymers, Silverman built much of the nuclear program from the ground up, including the University's first radiation facilities and supporting laboratories, and the program's first curriculum. Dr. Silverman published hundreds of papers on radiation chemistry and radiation engineering, radiation-induced polymerization, radiation modification of polymers, pulse radiolysis, and nuclear engineering. During his tenure, he directed more than 40 Ph.D. dissertations, and tens of M.Sc. theses. He received a Lifetime Achievement Award for his fundamental and applied work in radiation physics and chemistry at the 9th International Symposium on Ionizing Radiation and Polymers in 2010 [42]. Professor Silverman was always kind, thoughtful and considerate. He died in November2019 at the age of 97.

Vivian Stannett (1917-2002)

IMRP Laureate 1984



Vivian Stannett was a prominent polymer scientist and engineer who used radiation to develop flame-resistant textiles, plastic bottles that prevent soft drinks from going flat, and super-absorbent paper towels and diapers. He researched chemical modifications of cellulose and investigated the application of polymers to textiles, pulp, and paper.

Born and raised in England, Vivian Stannett moved to the United States after World War II and received his Ph.D. in physical chemistry in 1947. In 1950, Vivian became a research associate at what is now the Carnegie Mellon University in Pittsburgh before becoming a professor at the College of Forestry in Syracuse, New York. In 1958, during a sabbatical, he partnered with Professors Adolphe Chapiro and Michel Magat at the University of Paris who worked in the field radiation grafting and radiation chemistry of polymers. In 1961, Stannett was appointed to associate director of the Camille-Dreyfus Laboratory for Polymer Research and then became a professor at Duke University and North Carolina State University.

Vivian Stannett published over 400 papers and reviews on polymer science and technology and received many distinctions [43].

Adolphe Chapiro

Adolphe Chapiro was born in 1924 in Moscow, in the former USSR. He arrived in France in 1933 and received his Ph.D. in chemistry at the University of Paris in 1950. Most of his long career was spent at the Centre National de la Recherche Scientifique (CNRS) near Paris. His contributions to the advancement of radiation-initiated polymerization and radiation grafting were major.

In 1949 Dr Chapiro published his first article on polymerization by gamma radiation [44]. His first paper on polyethylene grafting appeared in a publication in 1958 [45]. In 1962, Chapiro published Radiation Chemistry of Polymeric Systems (Interscience, New York), one of the earliest books on the topic.

A great collector of watches, Adolphe Chapiro also wrote an authoritative book on ancient watches: La Montre Française du XVIè Siècle Jusqu'à 1900 (Editions de l'Amateur, 1991).

Medical Device Sterilisation

It is no coincidence that radiation sterilisation – like ethylene oxide sterilisation – emerged in the 1950s. Inexpensive plastics were becoming available, opening the way to a revolution in healthcare; disposable medical devices started to replace resterilisable items. Besides reducing infection risk, single use devices were also lifting the heavy burden of cleaning, maintenance, and sterilisation off the backs of hospital personnel.

The first commercially sterilised product was an eye ointment, but the first medical devices commercially radio sterilised from 1956 were sutures manufactured by Ethicon Inc. in the USA. Heat sterilisation was not satisfactory for sutures: it adversely affected product quality and restricted the choice of packaging material [46]. Irradiation took place in Sommerville, New Jersey, first by electron beam and a few years later by gamma radiation.

The new sterilisation method had been developed by Charles Artandi and his team who produced major studies on the effects of radiation on a wide range of microorganisms found on medical devices, on suture materials and a great variety of packaging materials. Artandi also completed biological safety tests and clinical studies. He could eliminate the use of glass tubes for sterilisation and use more convenient and less expensive packaging materials instead, like aluminium foil and various laminates.

From the study of over 150 different species of microorganisms, Artandi and Van Winkle concluded that a dose of 25 kGy (2.5 Mrad) was 40% above the minimum required to kill the most resistant microorganisms [8]. This dose of 25 kGy remained the universally accepted sterilisation dose for decades, except for a few countries. The Scandinavian public health authorities recommended a minimum dose of radiation of 35 kGy for a bioburden below 50 per item, 45 kGy between 50 and 500, and 50 kGy between 500 and 5,000 [25].

The UK was a pioneer and early adopter of radiation sterilisation. As early as 1952, experiments were carried out by J.O Dawson and A. Charlesby on the sterilisation of sutures [24]. Accompanying the birth of a business for pre-packed sterile single use medical devices, significant quantities were sterilised at the UKAEA Wantage facility where extensive studies had been carried out. In 1961, Darmandy et al. confirmed the suitability of 25 kGy as a sterilising dose and suggested the use of *Bacillus pumilus E601* as a test organism for the efficacy of the treatment [47].

In 1963, the team published a book entitled Massive Radiation Techniques, a collaborative work edited by S. Jefferson, which, according to the UK Panel, remained the textbook for all those interested in the topic.

The first international conference on the radiation sterilisation of medical supplies was held at Risø, Denmark in 1964 with participation from 14 countries. With the aim of establishing international rules for the application of ionising radiation for sterilisation of medical products, the IAEA proposed a Recommended Code of Practice for Radiation Sterilisation of Medical Products at an international symposium in Budapest in 1967.

Many countries recognized the usefulness of the Code and adopted parts of it into their regulations governing sterility control. The IAEA published a Manual on Radiation Sterilisation of Medical and Biological Materials, which along with training courses organised in Mumbai (1969) and Buenos Aires (1971) contributed to the dissemination of the technology.

Before ISO 11137 standards became a universal reference for the validation and routine control of radiation sterilisation, there were many debates which appear irrelevant today. In the 20th century, they required long battles in some countries.

- Transiting from the concept of absolute sterility to sterility assurance level. It is in Scandinavia that the concept of safety margin – a numerically defined probability of non-sterility was first introduced in national regulations [48]. The concept of Sterility Assurance Level (SAL) was refined later. This was uncomfortable for those who preferred a 'clear' answer as to whether a product is sterile or not.
- Abandoning sterility tests on a given number of samples taken from routine batches.
- A reasonable number of sterility tests can detect only gross contamination or serious failure of the sterilising process. But this was an old practice that gave a sense of security, no matter how false it was.
- Releasing sterilisation batches on the base of dosimetry
- Discontinuing the use of biological indicators to control the efficacy of routine sterilisation processes.

Before 2000, John Masefield began to promote the idea that not all medical products needed a SAL of 10-6 and that SAL should consider how the product is used, but this battle has not been won yet.

Two other great contributors to the science of radiation sterilisation must be mentioned: Alan Tallentire and James Whitby.

Alan Tallentire (1929-2022)

IMRP Laureate 1999

Microbiologist, Emeritus Professor, University of Manchester, School of Health Sciences, Division of Pharmacy & Optometry.

Alan Tallentire was a prominent figure of radiation sterilisation from 1963 when he started as an advisor to the Food and Medical Group at the UKAEA Wantage Research Laboratory. He has held various positions at the UK Panel on Gamma and Electron Irradiation, the UK Association for Radiation Research, and the International Association for Radiation Research. He published many important papers and spoke at events around the world for five decades.

The influence of the product bioburden - and the importance of controlling it – for the efficiency of sterilisation was well understood early. It was obvious that a 'one size fits all dose' was not satisfactory, no matter how well accepted this dose had been. There was a need for a method, simple if possible, to determine the sterilisation dose on a case-by-case approach. Such a method might sometimes lead to lower sterilisation doses that would be less damaging for some materials, and as a result the range of radiation sterilisable products might be broadened. It is Alan Tallentire who, in the 1970s, published several articles [49, 50, 51] which proposed the basis of the dose setting methods that are used today and that were first published by AAMI before being incorporated in the ISO 11137-2 standard.

James Whitby (1925-2016)

IMRP Laureate 2006

James Lyndall Whitby was professor of microbiology at the University of Western Ontario, Canada. He was born in Hampstead, London, in 1925, and educated at Eton College, King's College, Cambridge and Middlesex Hospital Medical School, and qualified with the MB BChir in 1948. After various posts in the UK, in 1971, James was appointed as a professor of microbiology to the newly opened University Hospital on the campus of the University of Western Ontario, in London, Ontario. He became Professor Emeritus in 1990 and retired from the position of chief of microbiology in 1993 [52]. In his later years, his main interest was the radiation sterilisation of medical devices.

James Whitby carried out extensive studies on the radiation resistance of microorganisms found on medical devices, which contributed to the development of standardised protocols for dose setting methods. They were first extensively presented in 1981 during a conference sponsored by Johnson & Johnson and later refined [53]. James and his wife played chamber music and amassed a rich collection of antiquarian chamber music, which they left to the libraries of Western Ontario University.

Food Irradiation

Samuel Goldblith, the American food scientist who developed radiation sterilized food for the NASA space program at the MIT, stated in 1970: "Never in the history of man has any method of food processing invoked so much comment, induced so great a controversy, nor required such an expenditure of funds before its use could be permitted even on a limited basis as has the use of ionising energy". Unfortunately, half a century later, this statement remains valid.

In the 1950s, it was generally thought that the most significant application for ionising radiations would relate to the preservation of food. Many research irradiators were built whilst research programs were launched in numerous countries. The earliest and most ambitious program was certainly the program of the US Army Quartermaster Corps, but there were also significant research programs at the Low Temperature Research Station in England, at the Federal Research Centre for Food Preservation in Karlsruhe, Germany, at the Nuclear Research Centre of Cadarache in France, and elsewhere in Europe.

The German spice company Gewürzmüller was the first in the world to build its own food irradiator, a Van de Graff machine installed in Stuttgart in 1958, just when Germany banned irradiation of food. That same year the US Congress passed the Food, Drug and Cosmetic Act. Ionising radiation would be treated as a food additive and the part of the Act known as the Delaney clause would ensure that no food would be irradiated unless this was specifically authorised. Many other countries felt that it was probably the right thing to do, so the impact of the Act was devastating and is lasting to this day.

This did not totally dampen the faith in the future of food irradiation.

In the early 1960s, mobile irradiators were constructed to demonstrate the potential of food and to gain practical experience by bringing the irradiators to the point of use. Fish irradiators were also constructed on vessels: an AEG X-ray machine on a fisheries vessel in Germany and a portable Co-60 irradiator on a vessel for Atlantic coastal fisheries in the USA [34].

Several countries (Canada, France, Italy, Japan, Spain, USSR, Uruguay, USA, etc.) permitted irradiation of potatoes, a low dose application, to inhibit sprouting during storage. In Canada, a mobile demonstration Irradiator was built by AECL in 1961. Consisting of a fully equipped and shielded 41 metric ton trailer which could travel by truck, train or ship, the Mobile Demonstration Irradiator went into action in October 1961, on a farm operated by Ottawa River Farms Limited, near Alfred, Ontario. The huge device could treat approximately 1.15 tons of spuds per hour, each tuber being exposed for four minutes or so [2]. Another irradiator on wheels using 175,000 curies of cesium-137 named Irma was built in France at the initiative of Conservatome.

In 1964, Newfield Products, created by John Masefield in Canada, started to irradiate potatoes on a commercial scale, with the objective of reducing potato imports from the United States during the period between the two Canadian crops as they were 2 to 4 times more expensive than local ones. An unprecedented wet season ruined the 1965 potato crop, and the fledgling irradiation business [54].

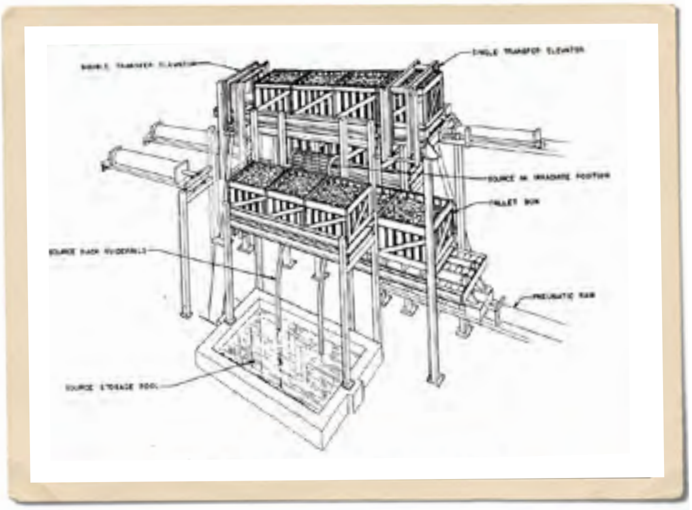


Figure: The source pass mechanism of the Newfield Products irradiator

Another potato irradiator would be created in Japan in 1976 with very limited commercial success. Little is known of the accelerator that was used for the irradiation of grain. It operated for a few years in the port of Odessa. Around 1970, a grain irradiator in Iskederun, Turkey, and a potato irradiator at the Fuccino cooperative in Italy were prevented from starting operation.

A remarkable project was the Pilot Plant for Food Irradiation (Proefbedrijf Voedselbestraling known as Provo) that started in Wageningen, Netherlands in 1968. With 100 kCi of cobalt-60, its main objective was to bridge the gap between laboratory work and practical application. The existence of this facility is the reason why the Netherlands would become a leader in food irradiation. A host of food products could be test marketed thanks to Provo.

It is also where what later became known as the Radura logo was created, initially intended as a mark of quality rather than a distinctive sign.

Radura is the combination of RAD for radiation and DURA meaning lasting in Latin. The dot and two leaves evoke a plant in a closed package (the circle) penetrated by ionising radiation (the breaks in the upper part of the circle). It might also be that the central dot is the radiation source, the two leaves are the biological shield, and the outer ring the transport system, the lower half of it being shielded from radiation [55]. The Provo facility was the anchor point for the International Facility for Food Irradiation Technology (IFFIT), a joint research and training program of the Dutch Institute of Atomic Research in Agriculture, the Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA) and the Dutch Ministry of Agriculture and Fisheries. Between 1978 and 1990, hundreds of engineers and scientists from about fifty countries carried out research and were trained in all aspects of food irradiation: technology, economics, or feasibility. During its 12 years of existence, IFFIT had two directors: Ari Brynjolfsson, from Denmark, and Josef Farkas, from Hungary.

Proving that irradiated foods are safe would undoubtedly be a long and expensive journey. The international scientific community joined efforts and cooperated within the framework of the International Food Irradiation Project (IFIP) based in Karlsruhe, Germany, who coordinated the research efforts. A Joint FAO/IAEA/WHO Expert Committee on Food Irradiation (JECFI) formed in 1969, would periodically review the enormous amount of data being generated. Other studies were carried out independently from this project, for example in China with human volunteers. One study worth a special mention is the Raltech study of the US Army Medical Department that lasted 7 years, used 230,000 chilled eviscerated broilers and cost 8 million dollars. Consisting of 20 separate research projects, it examined the effect of consuming radiation sterilised chicken meat, with respect to nutritional quality, teratogenicity, toxicity, carcinogenicity, reproductive performance and genetic toxicity on dogs, rats, mice, hamsters, rabbits, and vinegar fruit flies [56].

In September 1980, the JECFI concluded that irradiation of food at an overall average dose up to 10 kGy presents no toxicological hazards and introduces no special nutritional or microbiological problems. According to the Joint Expert Committee, toxicological testing of foods irradiated up to 10 kGy was no longer required.

For many, this was a major achievement that would - finally - lead to the commercial take-off of food irradiation.

The international cooperation that had been so successful was continued with a new project: the International Consultative Group on Food Irradiation (ICGFI) created at the initiative of FAO, IAEA and WHO. The Joint FAO/IAEA Division in Vienna provided the secretariat, with Paisan Loaharanu, Head of the Food Preservation section, being the linchpin. The project lasted from 1983 to 2003. ICGFI was addressing international trade, legislation, applications, transfer of information, training, and generation of data.

Despite all the efforts that have been deployed, the use of irradiation for food has remained marginal. Many service facilities initially created to irradiate food had to turn to other products to survive. In-house food irradiation projects also failed. There were two in France in the 1990s. In Normandy, the renowned dairy firm Isigny Cooperative in Normandy could not make use of the gamma irradiator that they had built to guarantee the microbiological safety of their raw milk soft cheese camembert. In Brittany, SPI (Guyomarc'h Group) who installed an in-house accelerator to kill Salmonella in mechanically deboned poultry meat for raviolis or frankfurters ceased operation when their customers refused to write "irradiated" in the list of ingredients, as the new EU Directive would require.

Unfortunately, like 50 years ago, discussions on irradiated food still get stuck with questions on their safety, consumers acceptance, to mention the word irradiation on the labels or not. The process is still considered as a food additive in most countries. Food irradiation regulations were not harmonised, except in the EU where essentially herbs and spices only are permitted. The volume of food being irradiated remains low, except maybe in China.

So food irradiation is the most researched, the most discussed, and the least used food-process. The huge potential of the technique to improve food safety and reduce losses remains untapped. The recent good news however is the growing use of irradiation as a phytosanitary measure.

In the second half of the 20th century, food irradiation had many talented and passionate advocates beside Pierre Vidal, already mentioned.

Frank Ley

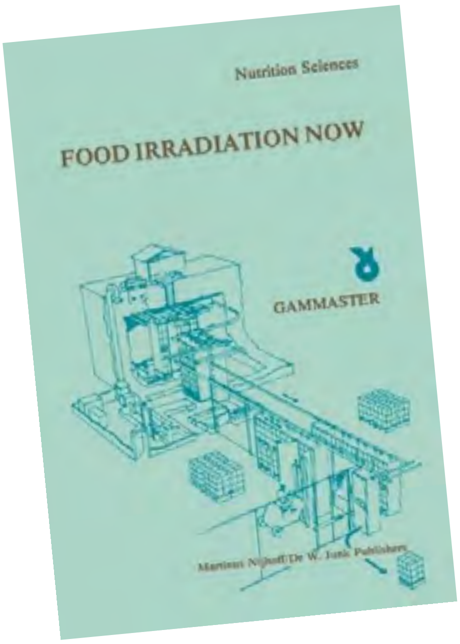
IMRP Laureate 1989

Born in Liverpool, England, Frank Ley was a member of the UK AEA at Wantage in the 1950s. His background being in microbiology, he had a passion for food irradiation, actively promoting its use during the early years. In the 1960s, he became involved in commercial irradiators projects in the UK. He was a founding director of Irradiated Products Limited later Isotron plc. Frank encountered considerable personal criticism from aggressive anti-irradiation lobby groups in the UK. Despite this, he remains a passionate advocate of the technology.

Jan Leemhorst (1938-2015)

IMRP Laureate 1994

Jan Leemhorst left Philips in Eindhoven, the Netherlands, to build and manage the irradiator of Gammaster in Ede. This was a project of the Dutch Cooperative of Pharmacists, OPG, who would sterilise their own products and offer spare capacity to third parties. The tote box irradiator that started in 1970 was soon insufficient. Since the demand for food irradiation was growing, supported as it was by the nearby Pilot Plant, a second irradiator was built. It was the first world pallet irradiator, at first met with a lot of scepticism by experts but adopted around the world a few years later. Before the new irradiator started operation in 1982, a successful food irradiation symposium was organised in late 1981. The book [60] became somewhat of a best-seller in the food irradiation literature and was even translated into Chinese a few years later. Its title Food Irradiation Now reflected the optimism and the determination of the symposium promoter:



Under the leadership of Jan Leemhorst, Gammaster was the first truly international irradiation company as it expanded in France and Germany in the 1980s, then in South Africa, Sweden and Thailand in the 1990s. Gammaster was later acquired by Isotron plc.

Jan Leemhorst is the person who propagated the Radura logo internationally by suggesting its inclusion in the Codex Alimentarius Standard for Irradiated Food as an option to label irradiated food. He tirelessly advocated food irradiation in multiple meetings around the world, often frustrated by the slow regulatory progress.

Frank Fraser (1935-2004)

IMRP Laureate 1989

Born in Montreal in 1935, Frank Fraser was a multi-sport athlete. His talents in football gave him a scholarship to Tennessee A&M where he also excelled academically, graduating with a B.Sc. He was a member of the Who's Who Among Students in American Universities and Colleges. Frank played in the Canadian Football League for 8 years (1956-1964) with the Montreal Alouettes, the Ottawa Rough Riders, Regina Roughriders, Edmonton Eskimos and the 1962 Grey Cup winners, the Winnipeg Blue Bombers. He joined AECL's CPD (later to become Nordion) on a part-time basis while at the same time juggling his football career and engineering studies. He became a permanent employee in 1964, started as Design Engineer and later became Vice-President Market Development. Frank was in the forefront of the design, supply and installation of many of the Nordion's industrial irradiation plants around the world. A passionate champion of food irradiation, Frank was Canada's representative and Deputy Chairman of the ICGFI. He was pivotal in establishing the Canadian Irradiation Centre in Laval, Quebec and the Food Technology Services Inc. facility in Tampa, Florida (later acquired by Sterigenics). Frank retired from MDS Nordion in 1998. Those who knew him appreciated his sharp mind, open spirit, enthusiasm, and keen sense of humour [2, 59].

Josef Farkas (1933-2014)

IMRP Laureate 1992

József Farkas was Emeritus Professor of Food Science of the Corvinus University of Budapest, Hungary, a part-time scientific adviser of the Hungarian Central Food Research Institute and a member of the Hungarian Academy of Science. From 1957 to 1986, he worked at the Central Food Research Institute in Budapest. From 1980 to 1985 he served as Project Director of the International Facility for Food Irradiation Technology in Wageningen, The Netherlands. József was editor-in-chief of the international journal Acta Alimentaria and the author or co-author of 12 books and several hundred scientific articles, many of them on food irradiation, especially spices and dried ingredients [58].

Cultural Heritage Preservation

The use of irradiation to preserve and consolidate artefacts is now an established application of irradiation. Recent IAEA projects and publications [61] have encouraged its development. Romania, Croatia, Brazil, South Korea, Vietnam, and Tunisia are among countries now using the method. The story started in the late 1960s at the Nuclear Research Centre of Grenoble in France.

In 1969, the City of Grenoble, France wanted to renovate a badly deteriorated 18th century parquet floor attributed to the highly regarded cabinetmaker Jean-François Hache and located in the marriage hall of the former Grenoble Town Hall, which was to become the Stendhal Museum. Louis de Nadaillac, an engineer of the Radiation Applications Section of the French Atomic Energy Commission (CEA) proposed to the local Department of Architecture and Buildings of France to adapt an industrial process for the manufacture of "plastic wood" to treat this floor, by impregnating it with a resin hardened in situ by gamma irradiation. The first industrial production of "wood-plastic flooring" had taken place in the USA in the 1960s and the technique had been studied in laboratories at the CEA in France and the University of West Virginia in the USA.

Louis de Nadaillac's original idea was to use and adapt the process to rescue badly deteriorated old wood, parts of which would otherwise have had to be replaced by a copy. Convincing his colleagues of the relevance of this idea was difficult. On the one hand, he had to persuade the rather conservative local authority that this new method would make it possible to preserve the authenticity of an important element of local heritage. On the other hand, he had to persuade a CEA laboratory to take the risk of investing in a pilot chemical treatment installation at an irradiator. He eventually managed to implement this treatment on an almost industrial scale. His Radiation Technology Group's engineering skills enabled Louis de Nadaillac to resolve the initial technical difficulties. The success of this large-scale treatment served as a springboard for Nadaillac to enthusiastically develop a larger project and to lead a small team in what was still an adventure in 1970.

Louis de Nadaillac

The success of this first project attracted the interest of other heritage conservation authorities. At the instigation of the Director of the

International Council of Museums (ICOM), Hugues de Varine, experts met in June 1970 in Grenoble to assess the possibilities of the new technique to conserve cultural property. Four international working groups were formed: damaged wood, stone, immersed wood, paper and fibres. Louis de Nadaillac involved major European heritage conservation organisations such as the International Centre for Conservation (ICCROM) in Rome, and the Institut Royal du Patrimoine Artistique (IRPA) in Brussels.

In 1971, a test program was carried out on samples of wood, stone, ethnographic materials, waterlogged wood, and paper, supplied by the different participants, in collaboration with the research laboratory of the Department of Historical Monuments. That same year, a 14th century Virgin and Child from Burgundy was treated with a new polyester resin. This statue was presented at the "Atoms for Progress" exhibition during the World Conference on the Peaceful Use of Atomic Energy in Geneva. For the first time, the use of gamma rays for the conservation of a remarkable work of art from Burgundy was highlighted. The event received a large coverage by the French and the foreign press, and the statue became an emblem of the Nucléart program.

After initial enthusiasm, difficulties began. The long-awaited samples that were required to start the impregnation program were slow to arrive. Attempts to automate the extraction of water from waterlogged wood in the ternary phase were unsuccessful. The critical tone of an editorial published by the authoritative magazine "Connaissance des Arts" increased the difficulties associated with the development of the technology and challenged the credibility of the program. This was nearly fatal for Nucléart.

Fortunately, a meeting of the ICOM Conservation Committee in Madrid provided an opportunity to present the first convincing results to 300 conservation specialists. Louis de Nadaillac was invited to join various specialised commissions, including the Commission for "Stone Disease" of the Architecture Directorate. The Executive Committee of the ICOM Conservation Committee created a working group on "Nuclear applications in conservation" and entrusted him with its coordination.

A first agreement between CEA and Direction des Musées de France was signed in 1973. That same year, Louis de Nadaillac was appointed Head of the "Nucléart project" created by the CEA with financial autonomy and the required flexibility to develop new programs.

The first consolidation of cabinet wood was carried out in 1973 on a shelf element with a decoration attributed to the Hache family of cabinetmakers. This consolidation was complementary to the work of a cabinetmaker-restorer. Then treatment of altered works began on a large scale.

The first results of the treatment of waterlogged wood were obtained in 1973 on objects from daily life extracted from the Colletière site (11th century) in the Charavines Lake in Savoy. A method of treating these woods was developed by successive baths of acetone to replace the water, and styrene-polyester resin to replace the acetone.

The irradiation treatment that received the most publicity was undoubtedly the disinfestation of Ramesses II's mummy. In 1974, Egyptologists visiting his tomb noticed that the mummy's condition was rapidly deteriorating and flew it to Paris for examination. Ramesses II was issued an Egyptian passport that listed his occupation as "King (deceased)". The mummy was received at Le Bourget airport, just outside Paris, with the full military honours befitting a king.

The mummy was examined by the French National Museum of Natural History. Having been damaged in the past by insect larvae, the mummy was also found to be infested by a dense population of various types of fungi, though without any pathogenic bacteria. In agreement with the Egyptian authorities, it was therefore decided to disinfect the mummy by gamma irradiation at the Nucléart laboratory. No sampling of the actual mummy of Ramses II was authorised, except for some fragments of hair and textile that were lying on the linen or on the Plexiglas plate placed under it. More than four hundred samples were taken from other lesser mummies to determine a dose effective enough to eradicate more than sixty species of fungi without harming the components of the mummy such as the hair, textiles, skin and teeth.

In 1973, Louis de Nadaillac prematurely died of leukaemia at the age of 36. Thanks to his competence, his dynamism, and his sense of organisation, in just four years he succeeded in establishing the foundations of Nucléart as the international reference [62, 63].

Annex 1: List of IMRP Laureates

Laureates	IMRP #	Place	Year
Charles Artandi † Paul Cooke †	2	Miami, USA	1978
William Baird † Arthur Charlesby †	3	Tokyo, Japan	1980
Toshikazu Higashino †	4	Dubrovnik, Yugoslavia	1982
John Masefield † Vivian Stannett	5	San Diego, USA	1984
Ken Morganstern V Joe Silverman †	6	Ottawa, Canada	1987
Frank Fraser † Frank Ley † Sam Nablo †	7	Noordwijkerhout, Netherlands	1989
Marshall Cleland † Joseph Farkas †	8	Beijing, China	1992
Jan Leemhorst † William McLaughlin † Pierre Vidal †	9	Istanbul, Turkey	1994
Sueo Machi † Arne Miller	10	Anaheim, USA	1997
Masaaki Takehisa Alan Tallentire †	11	Melbourne, Australia	1999
Joyce Hansen Robert Morrissey †	12	Avignon, France	2001
Yves Jongen George West	13	Chicago, USA	2003
John Corley Theo Sadat James Whitby †	14	Kuala Lumpur, Malaysia	2006
Dieter Ehlermann Rocco Basson †	15	London, UK	2008
Olgun Güven John Kowalski Wang Chuanzhen †	16	Montreal, Canada	2011
Andrzej Chmielewski Paul Minbiole	17	Shanghai, PR China	2013
Mohamad Al-Sheikhly Zhang Xianghua	18	Vancouver, Canada	2016
Maria Helena Sampa Yves Henon	19	Strasbourg, France	2019

† = Laureate is Deceased

Annex 2: The First International Meeting on Radiation Processing (1976)

The International Atomic Energy Agency must be credited for having organized the first three major international events in the field of radiation processing. These were:

- **Large Radiation Sources in Industry**
  Conference on the Application of Large Radiation Sources in Industry and Especially to Chemical Processes
  Warsaw, Poland 8-12 September 1959

- **Industrial uses of large radiation sources**
  Conference on the Application of Large Radiation Sources in Industry
  Salzburg, Austria, 27-31 May 1963

- **Large radiation sources for industrial processes**
  Symposium on the Utilization of Large Radiation Sources and Accelerators in Industrial Processing
  Munich, Federal Republic of Germany, 18-22 August 1969.

The first symposium dedicated to radiation sterilisation was organised on 7-8 December 1964 in Risø, Denmark, with the support of the UK Panel on gamma and electron. Ten years later, Johnson & Johnson sponsored a first international conference on Technical Developments and Prospects of Sterilization by Ionizing Radiation (Vienna, Austria, 1-4 April 1974), and held the First Kilmer Conference in East Windsor, New Jersey, on April, 30 - May 1, 1976.

The project to periodically hold a conference that would address all irradiation technologies and applications was formed by several people, among which John Masefield. The First International Meeting on Radiation Processing (IMRP 1) was held in Dorado, Puerto Rico at the Cerromar Beach Hotel on 10-13 May 1976. In retrospect, the punchline selected for the conference had something of a prophecy: Radiation's Time Has Arrived.

The meeting was sponsored by the American Nuclear Society, the American Chemical Society, and the Society of Plastics Engineers.

K.H. Morganstern (Radiation Dynamics) was Chairman of the conference and V.T. Stannett was Chairman of the program committee composed of A. Chapiro, A. Charlesby, W. McLaughlin, S. Okamura, J. Silverman, and Y. Tabata.

The table on the next page is a list of the presentations and speakers.

Basic concepts of radiation processing	J. Silverman
Crosslinking and degradation of polymers	A. Charlesby
Radiation initiated polymerization	Y. Tabata
Radiation grafting	A. Chapiro
Electron irradiation facilities	M. Ramler
Gamma irradiation facilities	R. Harrod
Radiation process control and equipment	R. Derbyshire
Shielding and safety requirement for electron accelerators systems	C.R. Hoffman
Radiation measurements and quality control	W.L. McLaughlin
Successful and promising application of radiation processing – Sterilization	C. Artandi
Preservation of food	J.F. Diehl
Applications of radiation processing in biomedical engineering	A.S. Hoffman
Sterility assurance of medical products	W.C. Dierksheide
Applications in plastic film and sheet	W.G. Baird
Applications in elastomers	G.A. Böhm
Irradiation in the production of communication wires	L.D. Loan
Applications in foam plastics	D.A Tregeser
Applications in wood plastics	A.E. Witt
Coatings applications	C. Coppinger
Radiation processing for textiles	W.K. Walsh
Ultraviolet applications for packaging	R.B. Mesrobian
Low energy electron process application	S.V. Nablo
Radiation treatment of sewage sludge – Experience with an operating pilot plant	A. Süss
Radiation treatment of combustion gases	S. Machi
Radiation treatment of solid waste	W. Brenner
Laser fusion sources for radiation processing	H. Gomberg

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