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Glenn Seaborg, The Periodic Table and a Belgian NGO

1. Introduction

Glenn Seaborg [1] was one of the greatest scientists of the 20th century, a chemistry Nobel Laureate who was responsible for the identification and production of plutonium and discovery of nine additional elements as well as for a major revision of the Periodic Table.

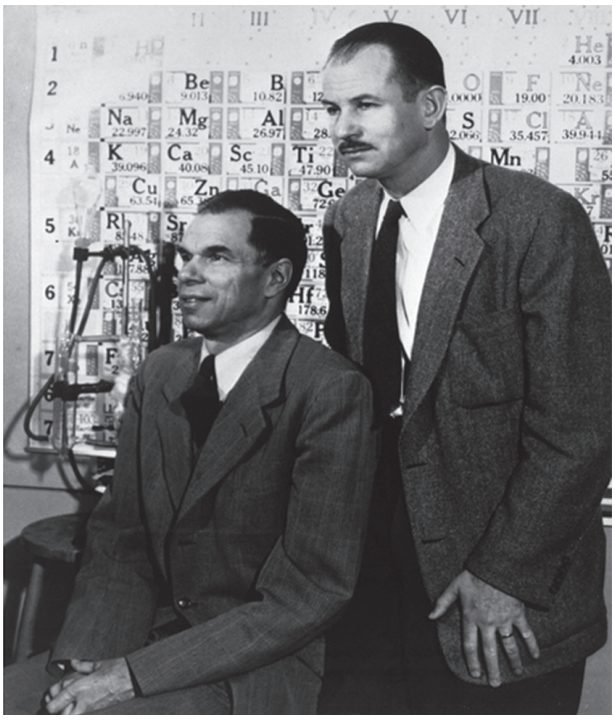
While his work on plutonium played a major role in the creation of nuclear weapons, he was personally profoundly committed to peace [2] and to the role that science could play in international development. In collaboration with the Belgian chemist Pierre Crabbé, Seaborg was a co-founder and became the first President of the International Organization for Chemical Sciences in Development (IOCD), an international nongovernmental organization (NGO) headquartered in Belgium.

Seaborg died in 1999 and the 20th anniversary of this event falls in the year designated by the UN as the International Year of the Periodic Table of the Chemical Elements, which celebrates the 150th anniversary of the publication of the landmark Periodic Table by Russian chemist Dmitry Mendeleev. The year also marks the 100th anniversary of the founding in Paris in 1919 of the International Union of Pure and Applied Chemistry (IUPAC), which has played a central role in the recognition and nomenclature of new elements. This triple, interconnected group of anniversaries provides the opportunity for a reflection on the contributions of the founding President to chemistry and global development and the legacy of the Belgian NGO he helped to create.

2. New elements and a revised Periodic Table

The American chemist Glenn Theodore Seaborg (19 April 1912 - 25 February 1999), whose mother had immigrated to the USA from Sweden, shared the 1951 Nobel Prize for Chemistry [3] with the physicist Edwin Mattison McMillan for their work on trans-uranium elements.

Glenn T. Seaborg looking at the first pure plutonium ($Pu(OH)_4$) produced from cyclotron at University of Chicago on August 20, 1942
Credit: Lawrence Berkeley National Laboratory



Glenn T. Seaborg (left) and Edwin M. McMillan in front of the Periodic Table, soon after the announcement of winning the 1951 Nobel Prize in Chemistry.
Credit: Lawrence Berkeley National Laboratory

Seaborg had gained a PhD in Chemistry from the University of California, Berkeley in 1937, having worked in the UC Radiation Laboratory (the forerunner of the Lawrence Berkeley National Laboratory) from 1934. He joined the UC Berkeley faculty in 1939. Seaborg led the team which, in 1941, accomplished the first chemical separation and positive identification of plutonium, element 94, a sample of which they created by the bombardment of uranium with deuterons in a cyclotron built by Ernest Lawrence.

Seaborg was subsequently responsible for isolating plutonium from the reaction products in newly devised uranium reactors, and for scaling up its extraction from ultramicroscopic laboratory amounts to a full-scale plant by what he called *"surely the greatest scale-up factor [10 billion] ever attempted"*. The plutonium was used in World War 2 in one of the first atomic weapons, the 'Fat Boy' nuclear bomb dropped on Nagasaki on 9 August 1945.

Seaborg went on to be co-discoverer of 9 elements beyond plutonium: americium (95), curium (96), berkelium (97), californium (98), einsteinium (99), fermium (100), mendelevium (101), nobelium (102), and seaborgium (106). These new elements were all created by high-energy particle collisions in nuclear reactors, particle accelerators, or nuclear explosions [4, 5] accomplishing a feat of transmutation of one element into another that had been the dream of the alchemists in their search

Group → / ↓Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

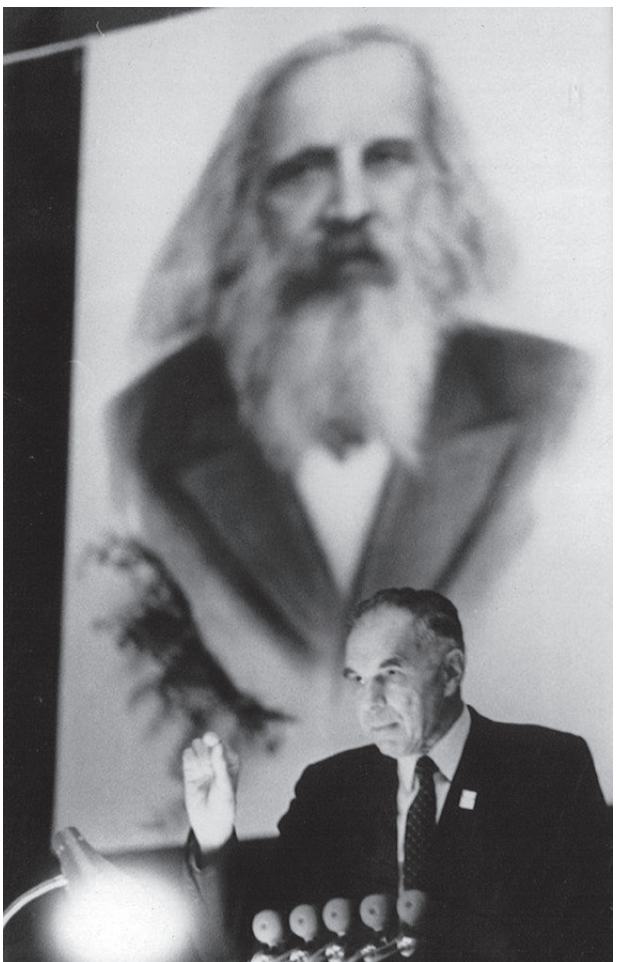
Actinide elements synthesised by Seaborg

Figure 1. Periodic Table of the Chemical Elements

for the 'Philosopher's Stone' that would turn base metals into gold. Indeed, later on Seaborg's group did produce minute quantities of gold by bombarding bismuth with high-energy carbon and neon nuclei [6] and he wryly titled a collection of his papers *Modern Alchemy* [7].

The eventual official naming of element 106 as seaborgium by the International Union of Pure and Applied Chemistry (IUPAC) in 1997, after a protracted period of controversy, was a particular honour since no element had previously been named after a living chemist.

A major step in understanding the theoretical underpinnings of the Periodic Table had been taken with the work of Henry Moseley, which established atomic number (the number of protons in the nucleus), rather than atomic weight, as the basis of ordering of the elements in the Periodic Table [8], with variable numbers of neutrons associated with the nucleus giving rise to more or less stable isotopes, and Moseley predicted that new elements would be found. Seaborg recognised that the 14 elements beyond actinium (89) formed a family, in the same way that the 14 elements beyond lanthanum (57) formed a 'lanthanide' series.



Glenn Seaborg during a lecture marking the 100th anniversary of the Mendeleev periodic table in 1969.
Credit: Lawrence Berkeley National Laboratory: Gift to IOCD of the deputy director of the LBNL Nuclear Science Division.

He first enunciated the 'actinide concept' in 1944, and this led to the first major revision of the structure of the Periodic Table (Figure 1) since Mendeleev's time.

Seaborg's work now established that the lanthanide and actinide series were distinct from the d-block elements and involve the filling of electrons into the 4f and 5f shells, respectively. Seaborg and his colleagues were also responsible for the identification of more than 100 isotopes of different elements throughout the Periodic Table and his host, the Lawrence Berkeley National Laboratory in Berkeley, California, leads the world rankings with the most (634 isotopes by 2011) discovered by any institution [9].

3. Public service: science, education and society

As one of the most prominent and well-known scientists of the period, Seaborg became heavily involved in public roles in the USA following his Nobel Prize. Named as one of the *"Ten Outstanding Young Men in America"* by the U.S. Junior Chamber of Commerce in 1947, at one time Seaborg was listed in the Guinness Book of World Records as having the longest entry in Marquis *Who's Who in America* [10]. He served as Chancellor of the University of California at Berkeley from 1958 until 1961, when he was appointed by President Kennedy [11] to the Atomic Energy Commission (AEC) and designated Chairman of the Commission, an appointment he held until 1971.

Seaborg advised ten US Presidents, from F. D. Roosevelt to G. H. W. Bush. He was a champion for science education. During the Eisenhower administration, he was appointed to the President's Science Advisory Committee, where he served as Chairman of the Panel on Basic Research and Graduate Education. The Panel produced the influential 'Seaborg Report' on *Scientific Progress, the Universities, and the Federal Government*" in November 1960. Its most

President John F. Kennedy and Glenn T. Seaborg at AEC Headquarters, Germantown, Maryland on February 16, 1961. Seaborg briefed the President on some nuclear energy fundamentals.
Credit: Lawrence Berkeley National Laboratory: Courtesy of the United States Department of Energy, Germantown, Maryland.
Photo by Elton P. Lord. Seaborg Lecture - My Service with Ten Presidents.

prominent recommendations were that the basis of general policy should be that basic research and the education of scientists go best together as inseparable functions of universities; and that federal support for basic research and graduate education in the sciences should be continued and flexibly increased, so as to support excellence where it already existed and to encourage new centres of outstanding work [12].

Appointed by President Ronald Reagan to serve on the National Commission on Excellence in Education, Seaborg was a forceful influence in toughening the critical stance that it took [13]. The landmark 1983 report [14] of the Commission, *A Nation at Risk: The Imperative for Educational Reform*, confirmed widespread, growing fears that US educational performance was declining [15].

This was *"in large part the result of disturbing inadequacies in the way the educational process itself is often conducted"*, with criticisms being levelled at educational content, expectations, the amount and effectiveness of time devoted to schoolwork and homework, and the training and professional conditions of teachers. Recommendations in all these areas were made and complemented by a call for better leadership, greater fiscal support and the acceptance by Federal Government of the primary responsibility for teaching. However, despite the immediate attention the Commission's report gained, many of its warning were not sufficiently addressed [16].

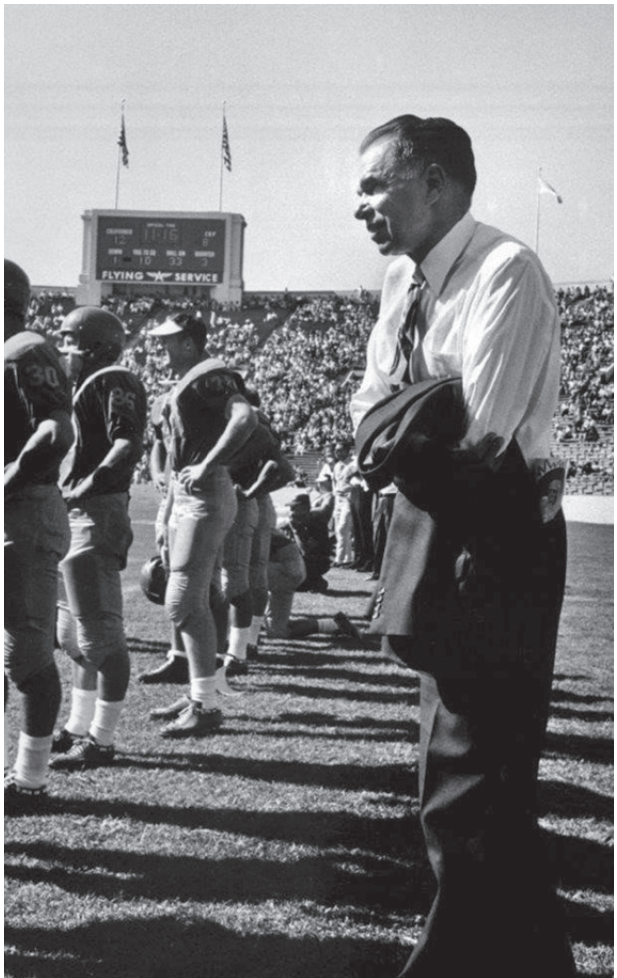
Other national positions Seaborg occupied included as President of the American Association for the Advancement of Science in 1972 and as President of the American Chemical Society (ACS) in 1976.

With a lifelong interest in athletics, Seaborg was an enthusiastic supporter of his university's sports teams, served on the Faculty Athletic Committee for several years and was the co-author of a book [17] concerning the Pacific Coast Conference

Glenn Seaborg presenting *A Nation at Risk* to President Ronald Reagan at the White House in April 1983.
Credit: Lawrence Berkeley National Laboratory

recruiting scandal, and the founding of what is now the Pac-12, in which he played a role in aiming to restore confidence in the integrity of collegiate sports [18].

Seaborg was a prolific author [19] and, in addition to more than 500 scientific papers and 40 patents, authored or co-authored about 30 books. These included both science texts and books aimed at a wider audience in which he described his experiences in the public service and political arena. His book *A Scientist Speaks Out: A Personal Perspective on Science, Society and Change* collected nearly forty of his more popular speeches and articles on a wide variety of topics, directed at a mostly non-scientific and non-technical audience [20].



University of California at Berkeley (UCB) verses College of Pacific football game at UCB Memorial Stadium on 20 September 1958, with Glenn Seaborg.
Credit: Lawrence Berkeley National Laboratory

4. International and humanitarian action

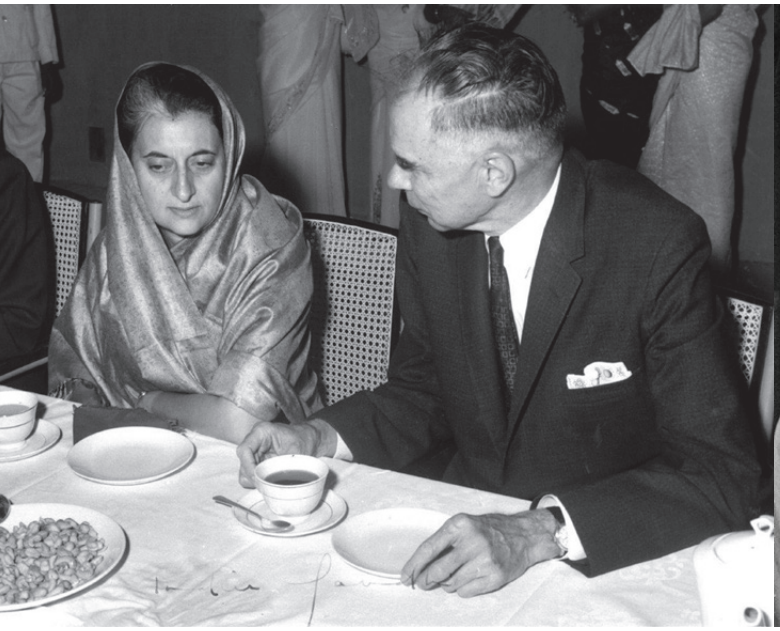
Seaborg was a major advocate for nuclear arms control, international cooperation in science, and conservation of natural resources [21].

Although participating in the Manhattan Project which built the USA's atomic bombs during World War 2, Seaborg was one of the scientists who put their name to the *Franck Report*, a secret document requesting that the bomb should not be used as a weapon [22]. They proposed, instead, that an atomic explosion should be publicly demonstrated in order to convince Japan to surrender, but this proposal was turned down. Subsequently, in his role as chair of the Atomic Energy Commission, Seaborg helped negotiate the *Limited Test Ban Treaty* of 1963, which secured the agreement of the UK, USA and USSR to ban testing of nuclear weapons in the atmosphere, in outer space and under water, as well as contributing to the 1968 *Treaty on the Non-Proliferation of Nuclear Weapons*. He was a strong advocate of a *Comprehensive Test Ban Treaty* [23, 24] and such a Treaty was adopted by a large majority of the UN General Assembly in 1996, although it has never come into force as not all the required Member States have yet signed and ratified it.

Seaborg emphasised the potential of nuclear energy to provide large amounts of energy cheaply and sustainably, frequently speaking and writing on the issue [25]. He led delegations to some sixty countries, including the USSR, India and China to promote the peaceful uses of atomic energy.

In 1981, Seaborg was one of 124 distinguished scholars, university presidents and organization executives from around the world who founded the World Cultural Council, whose objectives are to promote culture, values and goodwill throughout the world. One of the activities of the Council is to grant the Albert Einstein World Award of Science, the José Vasconcelos World Award of Education and the Leonardo da Vinci World Award of Arts to outstanding personalities whose work has had a significantly positive impact on the cultural legacy of mankind [26].

Seaborg worked industriously for international cooperation in science, seeing this a means of promoting peace and sustainable, equitable global development – and stressing the central role of chemistry. He summed up his reasoning as follows [27]:



Prime Minister Indira Gandhi and Glenn Seaborg at the dedication of Bhabha Atomic Research Center in Trombay, India in 1967.
Credit: Lawrence Berkeley National Laboratory (photo 7)

People's Republic of China Premier Zhou Enlai greets Glenn Seaborg, Peking 1973.
Credit: Lawrence Berkeley National Laboratory (photo 8)

"The world has reached a stage where substantial interdependence among developed and developing countries is essential to the fulfilment of human needs. We need to match-limited global natural resources-for providing energy, materials, food, and water-with the requirements of (growing populations). Too many people have too little food, are poorly clothed, live in inadequate houses, and have abysmal health care. We need to raise their levels of existence many-fold. The more affluent, meantime, face an uncertain future because of the stresses on their economies by the cost of energy. Everyone, meantime, will suffer from deteriorating environments.

In these efforts, chemistry, perhaps the most utilitarian of all sciences, and chemists and chemical engineers worldwide must play a vital role. Success will call for much greater international cooperation. Humanitarian instincts may be a significant motivating force, but inevitably so will our own self-interest. The economic and social futures of the advanced and the developing countries are inexorably entwined."

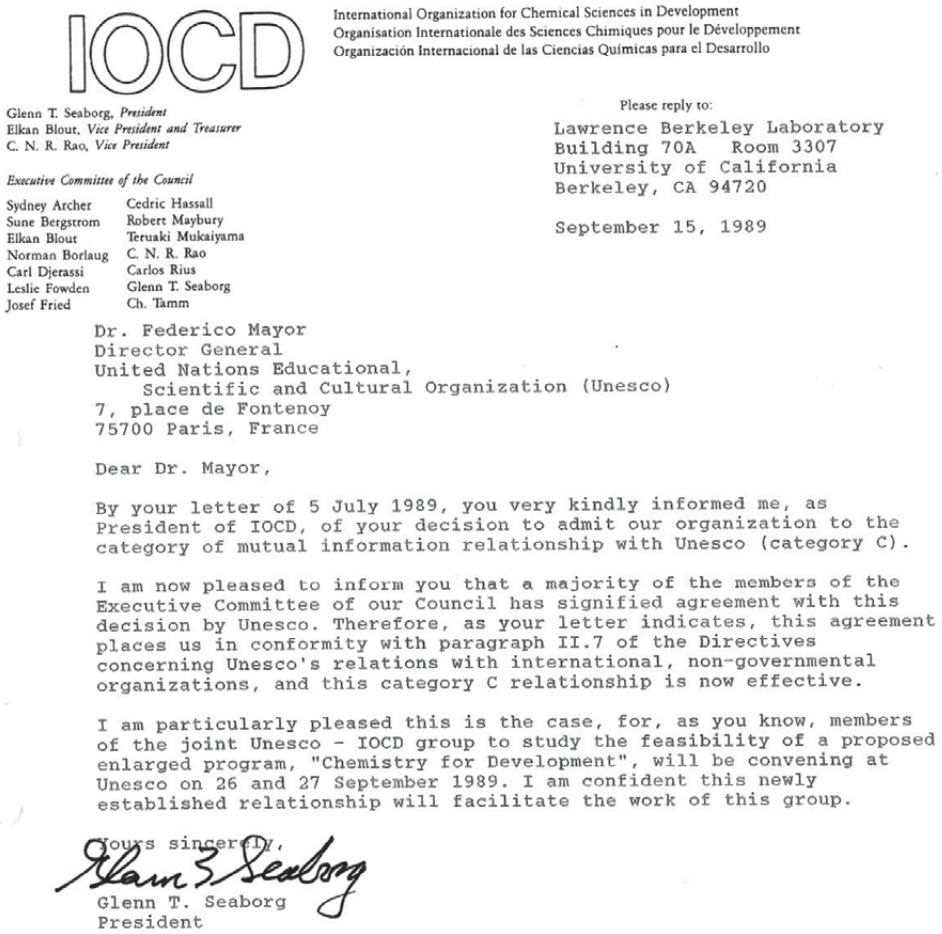
Among his many contributions to fostering international collaboration, while President of the ACS Seaborg proposed that chemists and chemical engineers could work together more effectively on matters with international implications if there were an international society to which they could belong as individuals. This led in 1981 to IUPAC introducing an Affiliate scheme to allow the world's chemists to participate in the Union [28]. Seaborg led a group of American chemists on a tour of government, university, and industrial facilities in China in 1978, at the time of opening up of US-China relations following China's Cultural Revolution.

5. Glenn Seaborg and IOCD

From the mid-1970s, the Belgian chemist Pierre Crabbé had been working towards the realization of his vision to build an international organization that would offer services and support to the chemical community around the world, fostering collaboration [29]. Following a decision by the 20th session of the UNESCO General Conference in 1978 that UNESCO should study methods of strengthening its programme of international cooperation in the chemical sciences, a number of studies and surveys were commissioned. A consultative meeting was held in Tenerife in September 1979 which recommended the establishment of an International Organization for Chemical Sciences in Development. The proposal was adopted by the 21st session of the UNESCO General Conference in 1980. At UNESCO's invitation, a group of scientists from 15 countries, including Seaborg, met at UNESCO in Paris on 2 July 1981 and set the constitution of IOCD.

IOCD was registered in Brussels as an international NGO, with Pierre Crabbé appointed as its Secretary-General (the title was later changed to Executive Director) and Glenn Seaborg elected as its first President [30]. Seaborg chaired the initial Executive Committee of IOCD, which also included two other Nobel Laureates, Sune Bergstrom [31] (Sweden) and Norman Borlaug [32] (USA), as well as other distinguished scientists, Elkan Blout (USA), Pierre Crabbé (Belgium), Sir Ewart Jones (United Kingdom), C. N. R. Rao (India) and Christoph Tamm (Switzerland) [33].

Seaborg remained President of IOCD until 1992, when he was succeeded by another Nobel Laureate, Jean-Marie Lehn [34]. During his period of office, Seaborg was a staunch supporter of IOCD, promoting its cause in talks and articles and seeking resources for its work and alliances with other bodies including UNESCO (Figure 2). In an article [35] in 1985, he wrote that *"we scientists fortunate enough to work in developing countries, with comparatively rich resources in education, facilities and funds, have a special obligation to share these resources and our energies with scientists in less developed countries and work together to seek solutions to the world's most pressing problems. Among these, problems are many areas (for example, improved control of disease and increased food production) whose solutions may well be reached through the field of chemistry"*.



IOCD

International Organization for Chemical Sciences in Development
Organisation Internationale des Sciences Chimiques pour le Développement
Organización Internacional de las Ciencias Químicas para el Desarrollo

Glenn T. Seaborg, *President*
Elkan Blout, *Vice President and Treasurer*
C. N. R. Rao, *Vice President*

Executive Committee of the Council

Sydney Archer — Cedric Hassall
Sune Bergstrom — Robert Maybury
Elkan Blout — Teruaki Mukaiyama
Norman Borlaug — C. N. R. Rao
Carl Djerassi — Carlos Rius
Leslie Fowden — Glenn T. Seaborg
Josef Fried — Ch. Tamm

Please reply to:
Lawrence Berkeley Laboratory
Building 70A Room 3307
University of California
Berkeley, CA 94720

September 15, 1989

Dr. Federico Mayor
Director General
United Nations Educational,
Scientific and Cultural Organization (Unesco)
7, place de Fontenoy
75700 Paris, France

Dear Dr. Mayor,

By your letter of 5 July 1989, you very kindly informed me, as President of IOCD, of your decision to admit our organization to the category of mutual information relationship with Unesco (category C).

I am now pleased to inform you that a majority of the members of the Executive Committee of our Council has signified agreement with this decision by Unesco. Therefore, as your letter indicates, this agreement places us in conformity with paragraph II.7 of the Directives concerning Unesco's relations with international, non-governmental organizations, and this category C relationship is now effective.

I am particularly pleased this is the case, for, as you know, members of the joint Unesco - IOCD group to study the feasibility of a proposed enlarged program, "Chemistry for Development", will be convening at Unesco on 26 and 27 September 1989. I am confident this newly established relationship will facilitate the work of this group.

Yours sincerely,

Glenn T. Seaborg
President

Figure 2. Letter from Glen Seaborg as President of IOCD to Federico Mayor, Director General of UNESCO, to acknowledge the partnership between IOCD and UNESCO. *Credit: Lawrence Berkeley National Laboratory and IOCD*

Many of Seaborg's personal ideals and aims are embodied in IOCD and continue to be reflected in IOCD's mission and activity as it goes forward. IOCD's work, undertaken through Working Groups and projects, initially focused on three areas: (1) research programmes on problems especially relevant to low-and middle-income countries (LMICs), with Working Groups dedicated to tropical diseases and agrochemistry; (2) provision of services, with analytical service centres being established in a number of high-income countries to assist chemists working in LMICs where they lacked local facilities; and (3) improvement of education in the chemical sciences, with the establishment of a Working Group to tackle this issue [36, 37].

By the mid-1980s, IOCD had moved from UNESCO headquarters in Paris and, with support from the Mexican government, established its Secretariat in Mexico City. Successfully attracting support and collaboration from a range of sources including UN agencies, other international agencies, governmental agencies and Foundations, the range of activities was expanded to include Working Groups and projects dealing with medicinal chemistry, fertility regulation, natural product exploration and exploitation, environmental analytical chemistry, the repair and maintenance of laboratory equipment and the need of libraries in LMICs for good quality textbooks, with the latter being supplied by IOCD through a book donation programme.

Following the death of Pierre Crabbé in a tragic road accident in Brussels in 1987, Robert Maybury was appointed Executive Director and the Secretariat moved to Washington DC. Since Maybury was succeeded by Alain Krief in 2010, the IOCD Secretariat has been based in Namur [38].

Over the years, IOCD has evolved and changed substantially, in keeping with the shifting

landscapes of science, international development and global challenges. With the world now focused on the collective responsibility that all Members States accepted in 2015 for achieving the UN Sustainable Development Goals (SDGs) for 2030, IOCD's orientation is now focused on engaging with global challenges. But it retains its emphasis on the involvement of chemists from LMICs and the overall contributions that the chemical sciences can – and must – make in accomplishing to sustainable development. IOCD currently focuses [39] on two strategic priorities, which continue to resonate strongly with the original founders' mission: (a) chemistry for better health and a better environment; and (b) strengthening education in the chemical sciences. These are pursued through Working Groups in Materials for Energy Conversion, Saving and Storage (MATECSS), and Education in the Chemical Sciences, as well as through a cross-cutting Action Group, Chemists for Sustainability (C4S).

C4S comprises an international group of chemists, with core members originating from Europe, India and Tunisia, who believe that chemistry and related sciences have indispensable roles to play in helping the world to achieve sustainable development. It serves advocacy and think-tank roles through written articles, lectures at various fora and web materials. Among the areas it has focused on have been the role of the chemical sciences in health [40] and in reaching the SDGs [41]; the need for chemistry to reposition itself as a science for the benefit of society through the adoption of 'one-world' chemistry principles and practice [42]; and the need to incorporate systems thinking into chemistry education, research and practice [43].

It was an especial pleasure for IOCD that the Chair of the MATECSS group, Federico Rosei, was awarded a UNESCO Chair at the Institut National de la Recherche Scientifique, Montreal; and that he was the recipient in 2014 of the World Cultural Council's José Vasconcelos World Award of Education, which Seaborg had helped to establish over 30 years earlier [44].

Following on in the pathways advocated by Seaborg, IOCD thus remains part of the lasting legacy to chemistry and to humanity that has been bequeathed by this giant of 20th century science.

Acknowledgements

The authors thank the International Organization for Chemical Sciences in Development for support, Alan Poon and Glenn Roberts Jr. of the Lawrence Berkeley National Laboratory (LBNL) for historical material and the LBNL for permission to reproduce photographs. This article is dedicated to IOCD's current President, Jean-Marie Lehn, in appreciation for his service since taking over the role from Glenn Seaborg in 1992.

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