Oscar Buneman and the Early Stages of Research on Cosmic Plasmas *

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Abstract

Fundamental knowledge about the cosmos, plasmas, fusion and fission was obtained in the 19th and early 20th centuries - interdisciplinary by astronomers, physicists, electrical engineers, chemists etc, and in close international contact. Most of the international contacts were interrupted by WWII and prohibited by the requirements of military secrecy during the following years of the cold war. In cooperation with other international organisations, especially the newly founded *United Nations Organization (UNO)*, the *International Astronomical Union (IAU)* played an important role in revitalizing international scientific exchange. The IAU organized several international conferences on the newly evolving research topic 'Cosmic Physics' which turned out to be very important for this field. Of special importance were the conferences 1949 in Como, 1956 in Stockholm and 1955 & 1958 in Geneva.

In a case study we describe the development of the field during the years 1941 to 1960 by following the scientific development of Oscar Buneman (1913-1983), one of the pioneers of cosmic and fusion-oriented plasma physics.

Zusammenfassung:
Oscar Buneman und die Anfänge der Erforschung von Kosmischen Plasmen
Grundlegende Erkenntnisse über den Kosmos, Plasmen, Kernverschmelzung und Kernspaltung wurden im 19-ten und frühen 20-ten Jahrhundert gewonnen - interdisziplinär (Astronomen, Physiker, Elektrotechniker, Chemiker etc) und in engem internationalem Austausch. Durch den 2. Weltkrieg und den kalten Krieg wurden die meisten internationalen Kontakte unterbrochen. Es war dann vor allem die *International Astronomical Union (IAU)* in Zusammenarbeit mit anderen Organisationen, insbesondere der neugegründeten UNO, die durch eine Reihe von Tagungen über das gerade entstehende Forschungsgebiet 'Kosmische Physik' den internationalen Austausch wiederbelebte. Eine besondere Rolle spielten dabei die Tagungen 1949 in Como, 1956 in Stockholm und 1955 & 1958 in Genf.

*slightly different version of pp. 490–515 in: Wolfschmidt, Gudrun (ed.): *Astronomie im Ostsee-Raum - Astronomy in the Baltic*, Proceedings der Tagung des Arbeitskreises Astronomiegeschichte in der Astronomischen Gesellschaft, Kiel, 13.-14. Sept. 2015; Hamburg: tredition 2018 (Nuncius Hamburgensis, Volume 38)

Die Darstellung der Entwicklung während der Jahre 1941 - 1960 lehnt sich an die berufliche Entwicklung von Oscar Buneman (1913 - 1993) an, einen der Pioniere der kosmischen und fusions-orientierten Plasmaphysik.

1 Plasmas

Today, the term 'plasma' (from Greek 'formed, shaped') is used in different meanings in the medical & bio-sciences, in mineralogy, and in physics. In this article we deal with plasmas in the sense of physics.

In 1928 the physicist-chemist-engineer *Irving Langmuir (1881-1957)* investigated oscillations 'in strongly ionized gases at low pressures, for instance in the mercury arc'. He observed

> Except near the electrodes, where there are *sheaths* containing very few electrons, the ionized gas contains ions and electrons in about equal numbers so that the resultant space charge is very small. We shall use the name *plasma* to describe this region containing balanced charges of ions and electrons.[1]

Langmuir also developed an instrument for measuring properties of plasmas, the *Langmuir probe*. Since Langmuir, the electron temperature of plasmas is measured in *electron-volt (eV)*, 1 eV $\approx$ 11600 Kelvin.

Plasma is the fourth state of matter: solid, liquid, gas, plasma - but the transition gas $\rightarrow$ plasma is different from the other two phase transitions. The transition from gas (only weakly interacting neutral particles) to plasma (charged particles interacting over the long range of Coulomb forces) may alter the properties of the particle system considerably. Thus many-body-interaction plays an important role. A possible charge separation gives rise to electromagnetic oscillations or waves, and many different instabilities may occur. Between a gas and a fully ionized hot plasma there are many different intermediate states of relatively cool partially ionized plasmas, and there are complex 'dusty plasmas', composed of a weakly ionized gas and charged microparticles.

Most of the visible matter in the universe is in the plasma state: there are e.g. fully ionized plasmas of high temperature and high density in the interior of the stars ($T_{sun} \approx 10^4 eV$), and fully ionized plasmas of low density in the atmosphere of the stars and in the space between them ($T_{some\ particles\ in\ space} \approx 10^{20} eV$).

On earth, there are hot plasmas in fusion-oriented experiments in laboratories, and there are low-temperature (partially ionized) plasmas in the flames of candles ($T_{flame\ of\ candle} < 0.1 eV$), in welding flames, in tubular fluorescent lamps, in mercury arcs, and also in certain tv-screens etc. The technological importance of low-temperature plasmas is growing: nowadays plasma processing is used to manufacture many products of daily life.

Though the term *plasma* was introduced already in 1928 in today's meaning, it took many years before it became common usage. During the years considered in this text, mostly the term *ionized gas* was used. An explanation for this is given by Alfvén in his book on cosmic plasma:

[1] Langmuir 1928, p. 628; 'sheaths' and 'plasma' emphasized by Langmuir, [Lan28]

Figure 1: The Saltsjöbaden Observatorium [(2013-09-21), `commons.wikimedia.org`]

It is situated in a beautiful surrounding on a peninsular about 20 km outside of Stockholm, close to the seaside resort Saltsjöbaden ('Salt Sea Baths') with grand hotel which was founded around 1893 and is connected to the city by train since then. The observatory was in operation in 1931-2001. Before, in 1753-1931, the Old Observatory was in operation, situated in the city. Now it is a museum. In 1931 to 1973 Saltsjöbaden Observatory belonged to the research institution of the Swedisch Academy of Sciences, then to Stockholm University, Department of Astronomy. The New Observatory (since 2001) is situated in the Alba Nova University Centre, operated jointly by the university and the Royal Institute of Technology (KTH). [Yas08, Soe18]

Plasma physics started along two parallel lines. One of them was the hundred-year-old investigations into what was called 'electrical discharges of gases'. To a high degree, this approach was experimental and phenomenological, and only very slowly did it reach some degree of theoretical sophistication. Most theoretical physicists looked down on this field which was complicated and awkward. The plasma exhibited striations, double layers, [...]. In short, it was a field which was not well suited for mathematically elegant theories.

The other approach came from the highly developed kinetic theory of ordinary gases. It was thought that, with a limited amount of work, this field could be extended to include ionized gases. The theories were mathematically elegant [...] all awkward and complicated phenomena which had been observed in the study of discharges in gases were simply neglected.

In cosmic plasma physics, the experimental approach was initiated by Birkeland[2], who was the first one to try to connect laboratory plasma physics and cosmic plasma physics. [...] Birkeland observed aurorae and magnetic storms in nature and tried to understand them through his famous terrella experiments (Birkeland, 1908). [...] research today essentially follows Birkeland's lines, especially in the respect that the contact between laboratory experiments and astrophysics is important [...].

Unfortunately, the progress along these lines was interrupted. Theories about plasmas, at that time called ionized gases, were developed without any contact with laboratory plasma work. In spite of this - or perhaps because of this - belief in the theories was so strong that they were applied directly to space. [...]. For thirty or fourty years, Birkeland's results were often ignored in textbooks and surveys, and all attemps to revive and develop them were neglected.

The crushing victory of the theoretical approach over the experimental approach lasted only until the theory was used to make experimentally verifiable predictions. From the theory, it was concluded that in the laboratory, plasmas could easily be confined in magnetic fields and heated to such temperatures as to make thermonuclear release of energy possible. When attempts were made to construct thermonuclear reactors, a confrontation between the theories and reality was unavoidable. The result was catastrophic. Although the theories were generally accepted, the plasma itself refused to believe in them. [...]. It was slowly realized that one had to develop new theories, but this time in close contact with experiments.

The 'thermonuclear crisis' did not affect cosmic plasma physics very much. The development of the theories continued because they largely dealt with phenomena in regions of space where no real check was possible. [...]

Another confrontation occurred when space missions made the magnetosphere and interplanetary space accessible to physical instruments. [...] Our picture of space around the Earth has changed radically in the past

[2] [Kristian Birkeland (1867 in Christiania (now Oslo) until 1917 in Tokyo)]

decades, as illustrated in Figure 1.2.[3]

Alfvén's Figure 1.2 is shown here as Figure 2.

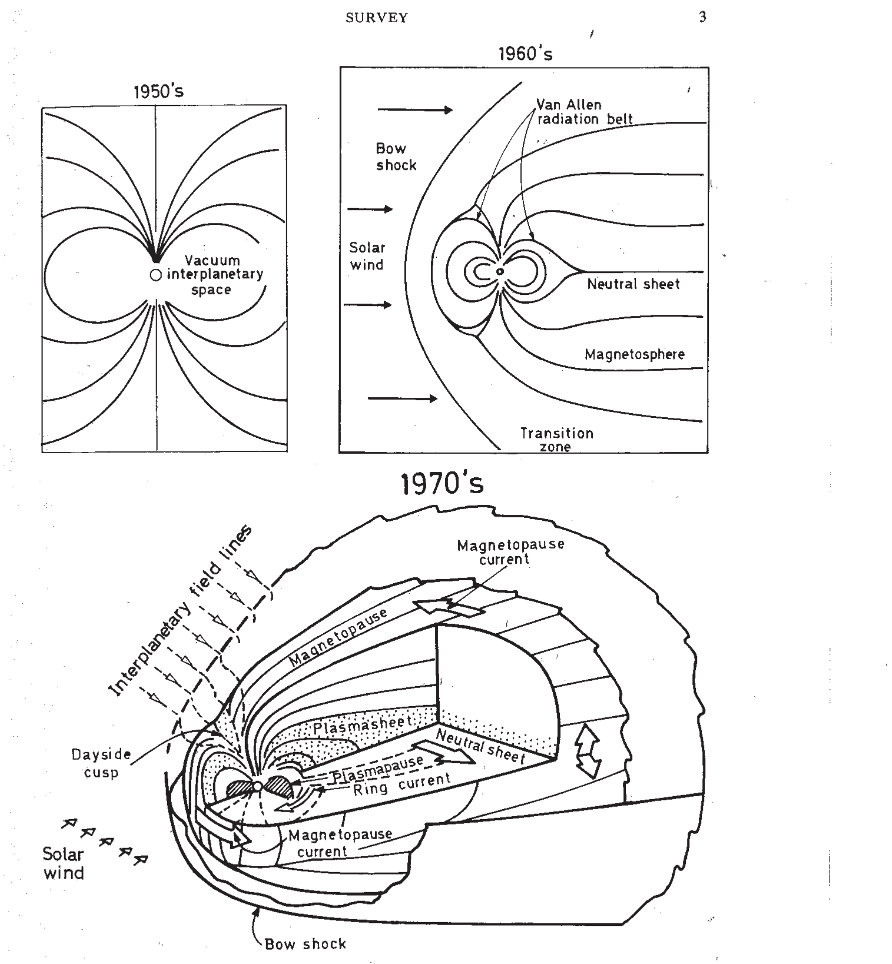

Figure 2: Changes of the picture of space around the Earth from the 1950's to the 1970's. Up to the beginning of the space age it was generally assumed that the Earth was surrounded by vacuum, and that its dipole field was unperturbed (except at magnetic storms). The first space measurements corrected that picture more and more [Figure 1.2, Alfvén 1981].

2 Discovery of fusion and fission

Important basic knowledge about the cosmos and about plasmas was attained during the 19th and early 20th century in exchange between scientists of different disciplines (astronomers, physicists, electrical engineers, chemists etc) and of different nations.[4]

[3] Alfvén 1981, Survey, chapter 1, pp.1-2, [Al81]

[4] Agnes Clerke 1887 & 1903 [Cl89, Cl03], Hannes Alfvén 1981 [Al81], Robin Herman 1990 [He90], David Fischer 1997 [IAEA97]

A first nuclear reaction was observed in 1917 by *Ernest Rutherford (1871-1937).* A first controlled fusion with gain of energy was observed in 1934[5]. A first controlled fission of a *heavy* atomic nucleus was observed in 1938[6] and theoretically explained a few months later[7]. Actually, the German chemist *Ida Noddack (1896-1978)* speculated already in 1934 that the element 93 could be split like the Lithium in the experiments by *John Douglas Cockcroft (1897-1967)* and *Ernest T.S. Walton (1903-1995)*, but nobody believed her[8].

World War II and the cold war following interrupted most international co-operations, but intensified research in these fields. In the years around 1950 *Plasma Physics*, an interplay of several different disciplines of physics and electrical engineering, evolved as a new discipline of physics. First the goal to construct hydrogen bombs dominated. This research was done in military secrecy. The work was *classified.* The first H-bombs exploded in tests in 1952 (USA) and 1953 (Soviet Union).

Around the same time, fundamental research on plasmas grew in importance: fundamental questions arose about beams and flows of charged particles in electro-magnetic fields, and cosmic rays and electro-magnetic phenomena in cosmic plasmas had to be understood. For instance it was known for some time that there is *some* connection between sunspots, solar flares and terrestial phenomena such as magnetic storms and aurorae. The role of electromagnetic fields was unclear for a long time: in *Agnes Clerke's (1842-1907)* modern textbook *Problems in Astrophysics* of 1906, the term *magnetic field* occurs only in one context, on 3 pages. She concludes that topic:

> The machinery by which electromagnetic impulses are propagated from the sun to the earth, completely evades scrutiny.[9]

Two years later, in 1908, *G.E. Hale (1868 - 1938)* discovered the magnetic fields of sunspots. The knowledge about interstellar fields developed between 1945 and 1949[10]. It was unclear how to explain cosmic radiation and its time variations. In 1956 there were still contradicting theories.

And then there was also the goal of *fusion reactors* for energy supply. This was a challenge for science *and* technology. In the countries of the allied powers, the research on high-temperature plasmas with goal fusion reactor was performed by the same research groups who worked on the hydrogen bomb - until 1958 in military secrecy, even between USA and UK, though they had cooperated in the Manhattan Project during the war.

> In 1950s, in the period when thermonuclear fusion only began to be perceived as a potential source of safe energy, the world was divided into two rival social systems. Because of the newly developed nuclear weapons, their military industries worked under extremely secret conditions, and any

[5] Oliphant, Harteck & Rutherford 1934[OHR34]. Paul Harteck was a visitor from Berlin.
[6] Hahn & Strassmann 1938 [HS39], Hahn did joint work with Rutherford in 1905-1906 in Montreal.
[7] Meitner & Frisch 1939[MF39]
[8] Cockcroft & Walton 1932 [CW32]; Noddack 1934 [No34]
[9] Clerke 1906, 2nd edition of [Cl03]
[10] H C van de Hulst In Lehnert 1958, pp 9-14 [Leh58]

> nuclear research was by default believed to have important military consequences.
>
> In this situation, scientists on both sides slowly realised that in the case of magnetically confined thermonuclear fusion there wasn't actually any potential for military exploitation. Although this message seemed suspicious to any non-expert politician, scientists pushed it hard, knowing the strength of a free and broad international science collaboration. [11]

It was strongly felt by many researchers that the international exchange of earlier years would speed up attaining the missing theoretical understanding. The knowledge on cosmic plasmas was not classified but freely published. This gave the opportunity to revitalize international contacts by a number of conferences.

It should be remembered that many of these researchers were Nazi-emigrants who had not been in their home-countries for many years. This gave an additional emotional importance to some of the meetings - these meetings gave the emigrants the opportunity to visit their former home countries again, and to meet again former colleagues and friends. As a case study, we describe the development of the field during the years 1941-1960 by describing the scientific development of Oscar Buneman. In Section 4 we deal with several of those early conferences.

3 Oscar Buneman (1913-1993)

When plasma physics and computational physics evolved as new fields in physics, Oscar Buneman happened to be in one of the centers of the new development, and he acted as one of their pioneers and founders. Also, he was involved in shaping the new face of nonlinear science and numerical analysis. These four fields did not evolve independently from each other: there are inner reasons why people like Buneman contributed to several of these fields at the same time.

Oskar Bünemann was born in Milano in 1913 with German citizenship. He obtained British citizenship in 1944 and changed his name to *Oscar Buneman* around 1950. In his youth, political events made him move from Italy to Germany (1915, World War I), to Manchester (1935, after imprisonment by the Nazis in 1934-35), to the Isle of Man, Canada, Liverpool and again the Isle of Man (interned 1940-41), to Manchester (1941-44, magnetrons) and to Berkeley, USA (1944-45, Manhattan Project). After that he joined the Canadian & British Atomic Energy Projects in Montreal (fall 1945 to spring 1946) and at AERE[12] Harwell (1946-1950). Then he became University Lecturer in Mathematics at University of Cambridge (1950-60), Prof of Electrical Engineering and Head of the Plasma Research Institute at Stanford University (1960-1984) and Stanford emeritus (1984-1993).

His emigration in 1935 shifted his scientific interest from *pure mathematics* during his studies in Hamburg (1932-34, goal: school teacher, close scientific and private contacts with *Emil Artin (1898-1962)*) to *applied mathematics*, *physics* and *electrical*

[11] EUROfusion 2010 [Ef10]

[12] AERE - Atomic Energy Research Establishment

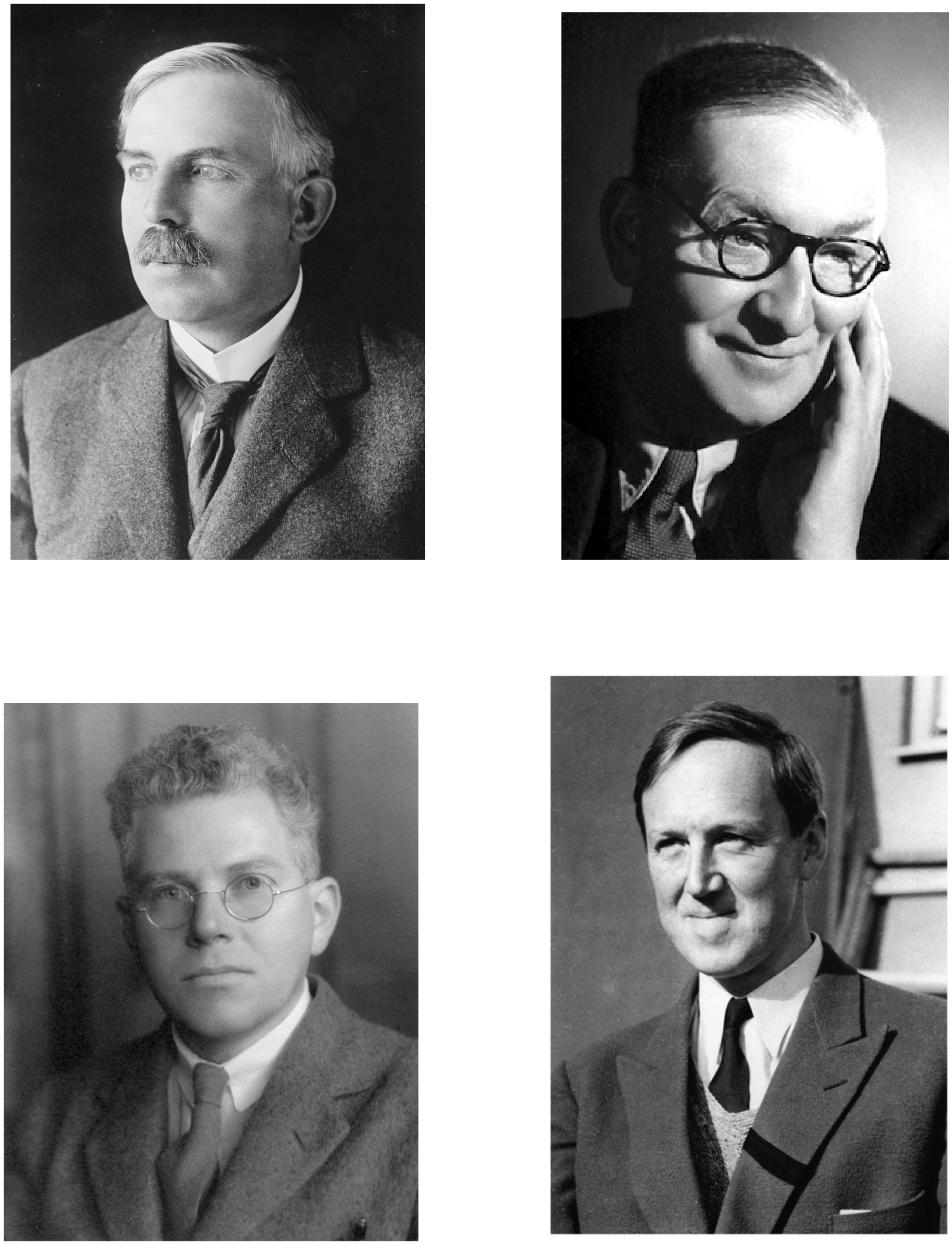

Figure 3: from left to right, top to bottom: Ernest Rutherford, 1st Baron Rutherford of Nelson (1871 at Brightwater, New Zealand – 1937 at Cambridge, England), *George Grantham Bain Collection (Library of Congress)*; Sir John Douglas Cockcroft (1897 at Todmorden, England – 1967 at Cambridge, UK), *Nobel foundation* - `https://nobelprize.org/`; Sir Marcus Laurence Elwin "Mark" Oliphant (1901 at Adelaide, Australia – 2000 at Canberra, Australia), *1939 by Bassano Ltd* `https://www.portrait.gov.au/`; Hannes Olof Gösta Alfvén (1908 at Norrköping, Sweden – 1995 near Stockholm), *1942 by unknown user at Grenoble* `http://www.osug.fr/`.

engineering in Manchester. Though he moved to Manchester because Artin's colleague *Louis Mordell (1888-1972)* was there, he got his Ph D with *Douglas Rayner Hartree (1897-1958).* Hartree himself got his PhD with advisor Ernest Rutherford with numerical work related to Bohr's atomic model. After release from internment Buneman joined the magnetron group of Professor Hartree, working for the British Admiralty. The task was to achieve a better understanding of the generation of microwaves in a cavity magnetron, to design a device for efficient production of radar waves (i.e. special microwaves) of wave lengths which the German Luftwaffe could not jam because they did not know how to produce them. Mathematically speaking, they computed the paths of *many* charged particles (an electron beam) in a given electro-magnetic field of a cavity magnetron, taking into account that the moving charged particles generate fields themselves. The resulting field is called a *self-consistent* field. One of the equations to be solved again and again was the *Poisson equation.* By observing the particles timestep by timestep, he discovered the 'threshold' criterion for magnetron operation, later on an important design tool.

It seems that Buneman's interest in astrophysics started in his youth. His wife Ruth later told:

> He taught me a lot about the stars. Moving from Germany to England to Canada as a young man, he felt it was wonderful that the stars were constant.[13]

The work in the magnetron group was a paid job. Thus he could afford to get married. In June 1942 he married *Mary Frances Behrens (1921- 2016)* of the well-known mercantile family Behrens of Manchester. They had two sons: Oscar Peter (*1943 in Manchester, now *Peter Buneman, FRS*) and Michael (*1945 in Berkeley).

The scientific expertise he gathered in the magnetron group had a deep impact on all of his subsequent scientific life. When the work of the magnetron group came to an end, Professor *Mark Oliphant (1901 - 2000)* invited him to join his group in Berkeley to work on 'ion optics', i.e. on the electro-magnetic separation of uranium isotopes with the CALUTRON *(California University cyclotron).* In a cyclotron, charged particles move in a given magnetic field. The paths of the particles depend on their mass – different isotopes move on different paths. Thus he probably computed there again paths of charged particles (ions) in their self-consistent fields. For being a member of the British delegation to the Manhattan project in Berkeley, Buneman attained British citizenship. He kept it for all of his later life.

When the Manhattan Project came to an end in the summer of 1945, it seemed clear to him that he would continue to work in the field of nuclear research. He accepted an offer to join the team led by Profs *John Cockcroft (1897 - 1967)* and *James Chadwick (1891 - 1974)* for the *Canadian and British Atomic Energy Projects.*

This project was started in the late thirties in England, moved to Montreal during the war, but was not intensely pursued during the Manhattan project. After the war it was intensified in Montreal, and its return to England was planned in Montreal.

It was clear that it would be too dangerous to do this work at a university in the middle of a city. So it was decided to found the new site *AERE Harwell* in the

[13]Stanford University News Service 1993 [Stan93]

countryside between Oxford and Reading, far enough away from a place with dense population, but close enough to a university for using their facilities (library, lecture halls, hospitals etc.), and to a military airport.

According to the public records in *The National Archives* [NaAr], while at Harwell Buneman did (secret, military) research on nuclear energy, fission and fusion, analytic and computational, and shared his knowledge in internal reports (two of which were declassified and published as articles in scientific journals later on) and in two series of lectures: four lectures on pile theory (1946) and seven lectures on *'Scientific and engineering problems of nuclear power'* (1949). In his reports he mostly dealt with pile theory, i.e. with devices for gaining energy from fission of heavy nuclei like uranium. But he also dealt with magnetron theory again (1948) and with *'The use of large-scale computing facilities in the theoretical analysis of light nuclei'* like the hydrogen isotopes which are important for controlled fusion (1950).

In 1948 Buneman was unhappy about his working conditions and about the topics of his work. He felt that

> [...] the possibility of making "fundamental contributions" in pile work and the scientific appeal of the work (limited in any case by the continued security restrictions) is decreasing rapidly [...].

He would have preferred to fully concentrate on the newly evolving field of plasma research and controlled fusion.[14]

Also, the private life of families was very much restricted by the military, and thus uncomfortable at Harwell: they had to live in prefabricated houses, *'tiny tin boxes'*, which gave the place *'the general appearance of a penal colony.'* Mary had a massive re-entry culture shock and remembered later:

> Never before had I felt so humiliated nor so homesick for the wonderful, convenient United States.[15]

The couple separated during their Harwell time and got officially divorced in September 1951. They both got remarried shortly afterwards: Mary in Oct 1951 to *Brian Flowers, Baron Flowers, FRS (1924 - 2010)* and Oscar to *Ruth Eades (*1929)* in April 1952.

The head of Buneman's department in Harwell was *Klaus Fuchs (1911 - 1988)*. When Klaus Fuchs was uncovered as a spy, security regulations were severely increased, and several people were advised to leave AERE. Among them was Oscar Buneman. He became university lecturer for mathematics at the University of Cambridge and a member of Peterhouse. His scientific interest, however, focussed on numerical methods (frequent interactions with his former teacher Hartree who was a professor at Cambridge now) and fundamental classical electrodynamics (contacts with *Paul Dirac (1902-1984))*.

> It was during this period that Buneman first turned his attention to electric phenomena in cosmic plasmas. He seized upon this subject in spite

[14] Buneman papers, Original and copy of a typewritten letter which was probably not sent, [buneman-papers]

[15] Mary Flowers 2009, [mary09]

Figure 4: Oscar Buneman and his son Michael in 1978, at the Buneman's home on one of the crests of Los Altos Hills near Stanford University. Michael has a chicken on his lap – several chickens lived in Buneman's garden to supply them with eggs. Many thanks to Michael Buneman for giving me a copy of this photo.

> of the lack of observational data supporting the notion of such phenomena in space beyond the earth's ionosphere. Oscar was an enthusiastic participant in numerous cpnferences devoted to theoretical developments in this then-infant science of space plasmas. He received a personal invitation from Hannes Alfven to attend the [IAU Symposium, Stockholm 1956. ...]. Over the years, Oscar continued his collaboration with many of the notables at this conference [...].
>
> By the mid-1950's, Oscar's hallmark trait of intellectual enthusiasm was allready well-developed. When a subject seized his interest, he threw himself into it – mind, body, and soul. It was not enough that he, himself, was excited about it; he insisted on exciting equal enthusiasm for it in his colleagues. In this spirit, Buneman joined forces with Alfven travelling together by train across Europe, advocating the importance of plasma, particle beam, and electromagnetic effects in space. [16]

In the academic year 1957/58 he spent a sabbatical at Stanford University. During this stay he had access to the biggest and fastest computer of the time, a Univac 1103AF. Extending the numerical methods employed earlier, he did a *first* numerical simulation of a plasma, computing paths of the same number (256) of positively and

[16] Ruth Buneman et al 1994, p. 23, [BBP94]; Until now, the present author did not find any documents about this joint trip of Buneman and Alfven in any archive.

negatively charged particles in a self-consistent field. Thus he discovered an electron-ion instability, called the *Buneman Instability* today. In this paper he discussed applications of his results to cosmic and to laboratory plasmas[17]. In 1960 he moved to Stanford and continued research in cosmic and magnetically confined plasmas until his death in January 1993. Among other achievements, he was the founder of the computer simulation using particles[18]. In fact Buneman remained so active after his retirement that even 6 articles appeared in 1994-1996 which were co-authored by him. At the 1993 IEEE plasma conference ICNSP[19] in the summer of 1993 Buneman was supposed to give the invited plenum opening talk of the meeting.

> [...] his chosen title reflected his lifetime work: "Simulation - From Electron Devices to Cosmic Plasma"[20].

Instead, his colleague *Bruce Langdon* gave a memorial talk[21]. Starting in 1998, a *Buneman Award* was awarded at the ICNSPs to honor him and younger colleagues for their achievements, see Figure 6. More details about Buneman are given elsewhere[22].

4 Important international meetings

As already mentioned at the end of Section 2, the knowledge on cosmic plasmas was not classified during WWII and the cold war, but freely published. After 1945 this gave the opportunity to revitalize international contacts by a number of conferences: some of them only among scientists in the western countries, others for participants from East and West and Neutral countries. Among others, there were symposia on *Cosmical Gas Dynamics* in Paris, F (1949), Cambridge, UK (1953), Cambridge, US (1957) and Varenna, I (1960).

Of special importance were the
International Congress for Nuclear Physics, Quantum-Electrodynamics and Cosmic Rays, Basle-Como, September 1949[23].
Symposium on Electro-Magnetic Phenomena in Cosmical Physics, Stockholm (KTH) 1956, Aug. 27-31; Sept. 1 (Sat) & 3 (Mon)
and two *United Nations International Conferences on the Peaceful Use of Atomic Energy*, Geneva 1955 and 1958.

4.1 Como, Sept 11-16, 1949

We confine here to part of the meeting *International Congress for Nuclear Physics, Quantum-Electrodynamics and Cosmic Rays,* Sept 11-16 at Como. It is counted as

[17] Buneman 1959 [Bun59]

[18] Hockney & Eastwood 1981 [HE81]

[19] ICNSP 1993 - International Conference on Numerical Simulation of Plasmas 1993

[20] Ruth Buneman et al 1994 [BBP94]

[21] Langdon 1993 [Lan93]

[22] Buneman 1990 [Bun90], Stanford 1993 [Stan93], Ruth Buneman et al 1994 [BBP94], Meyer-Spasche 2012 & 2014 [MSp12, MSp14], Meyer-Spasche & Nossum 2016 [MSpN16], and references therein.

[23] Programmes, list of participants and printed abstracts of the conference (including the abstract by Frisch) are available in the Otto Robert Frisch papers [CSAC]

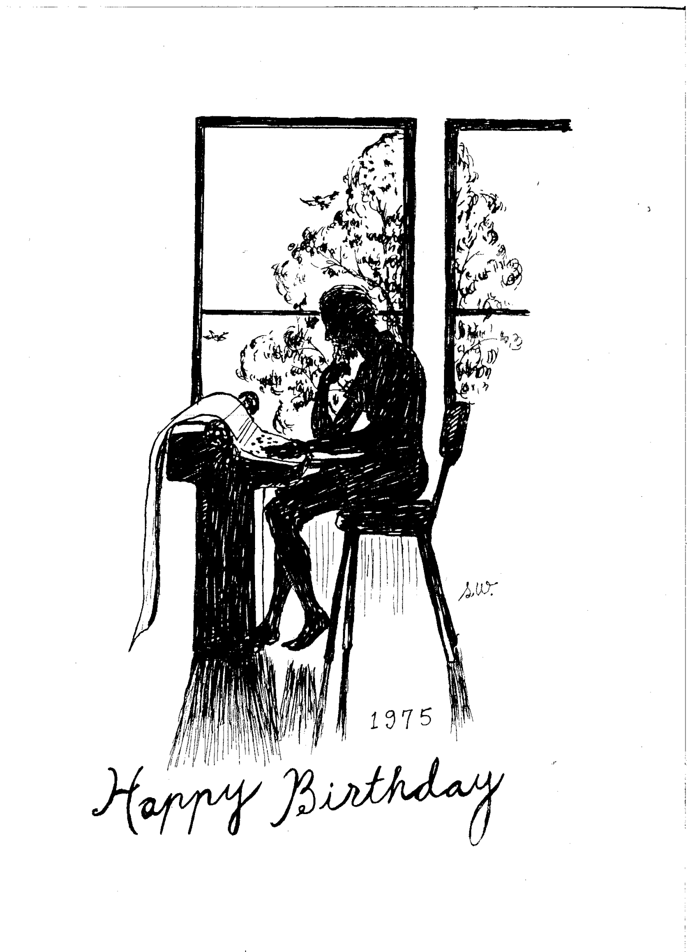

Figure 5: Buneman working at home, connected via a tele-typewriter (tty) to his computing center. In the 70's such connections were offered by big computing centers to their (priviledged) users. Drawing by one of his students (s.w.) and given to him as a birthday present in 1975. Many thanks to Ruth Buneman for giving me a copy of this drawing.

Figure 6: Oscar Buneman Award [Lan93, `oscar3m1.jpg`]

the *2nd International Cosmic Ray Conference, ICRC 1949*. Extended abstracts were published in advance (January 1949) and commented by colleagues with answers by authors. The first two entries are by Enrico Fermi and Hannes Alfvén, discussing both hypotheses about the origin of cosmic radiation[24].

This was the first time and only time that *Enrico Fermi (1901-1954)* returned to Italy from his exile at Chicago.

> Giorgio Salvini gave a touching report of the meeting between Fermi and Heisenberg: "Heisenberg and Fermi entered the hall from two opposite entrances, and greeted warmly after ten years of separation, during which they were engaged in competing, albeit similar programs. Historians, this is a meeting to remember, this cheerful meeting, in the presence of the best European physicists, winners or defeated. As if war had been eventually forgotten." [25]

The AERE Harwell colleagues Oscar Buneman, Brian Flowers and Bruno Pontecorvo went to the conference in the car of the Pontecorvos. They were joined by the wifes Mary Buneman and Marianne Pontecorvo at Como. In her partial autobiography, Mary Buneman (later Lady Mary Flowers) remembered in 2009:

> The second of these major international meetings of nuclear scientists was to coincide with the centenary of Volta's discovery of the battery. The Italians call it "pila", which caused some considerable confusion among the interpreters when delegates were discussing the atomic "pile", as a nuclear reactor was called in those days. [...]
>
> This was a time of great progress in the world of nuclear physics, and most of the leading scholars were gathered in hotels around the picturesque town and lake. Professors Fermi, Siegbahn, Alfven, Powell and Pauli were just among the many who had restarted their normal academic activities when the war finished, and were now leading research teams in what it was hoped would lead to the peaceful uses of the great new discoveries. It was a very special occasion, and one at which there was an air of celebration and of hope. I remember one grand ceremony in the town-hall of the historic town of Pavia, situated nearby. There, elaborately uniformed officials of the town made a formal procession before embarking on a series of theatrical orations such as the Italians love to deliver. In the middle of the proceedings the great Fermi was spotted, sitting in a modest seat, dressed overall in nothing more spectacular than his raincoat. With the sort of flourish usually seen only in a Verdi opera, the worthy burghers doffed their richly embroidered vestments. Almost on the verge of tears they welcomed their famous, if inconspicuous former fellow-countryman, and escorted him with embarrassing reverence to a seat of honour.

[24] Proceedings 2nd ICRC, [ICRC49]

[25] G. Salvini 2001 In: Celebrazioni del centenario della nascita di Enrico Fermi, Il Nuovo Saggiatore **16**, no 5-6, p 20; cited by Bruzzaniti 2016, p.43 [Bru16]

Apart from Fermi, who had been living in the United States ever since Fascism had made life difficult for him, and had there led the construction of the first ever atomic pile, under the football stadium in Chicago, there were a number of other Italians of repute among the delegates: Bernadini, Occhialini and one who was returning to his native country after a long absence, Giullio Racah. [...] There were banquets, boat trips on the Lake and excursions up the mountains, with no expense spared to commemorate and rejoice in the coming together of all these great figures. Everyone with something to contribute was roped in. The directors of the Olivetti typewriter company received us at their impressive factory at Ivrea, winding up the tour of their assembly lines by giving us a gastronomic lunch in a gargantuan assembly hall. In order to emphasize the European atmosphere of the occasion, the menu was written entirely in Latin. A smart and elegant Italian noblewoman who owned a superb villa high up on Monte Rosa gave a lavish cocktail party, causing those of us unused to drinking at an altitude of 12,000 feet to fall about in the snow while trying to walk back to the cablecars. The Casino at St Vincente offered a splendid dinner. Waiters processed with elaborately garnished silver dishes of lobsters and tournedos held high on their shoulders. After this epicurean orgy it was hard to stay awake during the flowery, theatrical speeches which seemed as if they would continue all night.

There were informal gatherings in hotels, restaurants and little street cafés as well.[26]

4.2 Stockholm, Aug 27-31, 1956; extended to Sept 1 & 3

This Symposium at the Royal Institute of Technology (KTH) on *Electro-Magnetic Phenomena in Cosmical Physics*[27] was most important:

> Much of the modern-day foundations of the plasma universe can he traced to the International Astronomical Union Symposium number 6 held in August, 1956, in Stockholm, Sweden, and attended by "Olympians" such as Alfvén, Artsimovich, *the Babcocks,* Baños, *Bennett*, Biermann, Hanbury Brown, Buneman, Burbidge, Chandrasekhar, Cowling, Dungey, Ferraro, *Fowler*, Gold, Hoyle, Lehnert, Parker, Pease, Piddington, *Pikelner, Schafranow, Shklovsky,* Schlüter, Spitzer, Swann, Sweet, van de Hulst, and many other notables.[28]

The symposium was organized by H Alfvén (Stockholm), chairman, L Block (Stockholm) and B Lehnert (Stockholm), secretaries, H W Babcock (Pasadena), L Biermann (Göttingen) and T G Cowling (Leeds). It got financial support from the International

[26] Mary Flowers 2009, pp 97-101 [mary09]

[27] The proceedings were edited by Bo Lehnert, 1958 [Leh58]

[28] Bostick 1989, abstract, [Bos89]; Italics by the present author: only H W Babcock is listed as participant, H D Babcock is coauthor of one of the papers; similar for the other names in italics: they are not listed as participants, but contributed to the proceedings.

Astronomical Union (IAU), the Union of Pure & Applied Physics (IUPAP), the Union of Geodesy & Geophysics (UGGI), from UNESCO funds; and from the Swedish Government and the Swedish company Ericsson.

At this symposium 86 leading astronomers, mathematicians, astrophysicists and physicists from 15 countries met (again), and some started new cooperations and friendships. Among them were five women, i.e. persons with non-abbreviated first names: Alice Daudin (France), Pamela Rothwell (Great Britain), Francesca Bachelet (Italy), Guro Gjellestad (Norway) and Aina Elvius (Sweden). The participants did not seem to be unhappy that knowledge close to classified work (and by participants from the Soviet Union even classified work) was discussed openly during this meeting. The chair Hannes Alfvén in his opening address:

> [...] our field now tends to become important even for the peaceful use of thermonuclear energy, which adds technological interest to the purely scientific interest[29].

46 talks were planned in advance. A chair and a secretary were elected for each session, Monday to Friday. In the proceedings not only talks are given, but also discussions. For correct reports on the discussions, notes were taken during the meeting, a tape recorder was used, and the comments were written down on special forms by the speakers taking part in the discussions.[30]

On Mo (27th), 7 papers were given and then a tour was arranged around the Department of Electronics. The current experimental work was shown: experiments on cosmic rays, electron orbits, plasma-resonance, magneto-hydrodynamics, and model experiments on the aurorae and magnetic storms. On Wed (29th), the participants went on an excursion to *Saltsjöbaden Observatory* and its beautiful surroundings, see Figure 1 and chapter 22 in these proceedings[31]. There was a talk on the history of the observatory, and then the instruments and some of the observational results were demonstrated to the visitors. Also, 8 papers were given on Wednesday. On Fr (31st), officially the last day of the meeting, 11 talks were given and two inofficial surprize performances were announced for Saturday, Sept 1st and Monday, Sept 3rd: talks on high current discharges by Golovin and Artsimovich, and 'a truly elegant auroral display': the Swedish Solar Observatory on Capri had identified a strong solar flare, and the Swedish scientists knew by experience that an aurora would follow 24 hours later. Many participants were still in Stockholm and took the opportunity to attend these additional attractions. Bostick was scheduled to leave on Saturday, so he missed part of the talks. But he could enjoy a beautiful aurora during his flight back to the USA.[32]

At the Como meeting in 1949, interpreters were employed during the meeting, and the proceedings volume contains contributions in several different languages[33]. 1956 in Stockholm, all participants of the regular part of the meeting spoke or wrote in English, also the Soviet participants - except Kipper from Tartu: his proceedings contribution

[29] Alfvén In Lehnert 1958, pp 1-2, [Leh58]
[30] Lehnert 1958, p.xi, [Leh58]
[31] Söderlund 2018, section 22.3.4 [Soe18]
[32] Bostick 1989, [Bos89]
[33] Mary Flowers 2009, p 97 [mary09]; Proceedings 2nd ICRC, [ICRC49]

gives title and abstract in English, but the main text is in German. Also the discussion following his talk was in German.

The surprize talks announced for Saturday and Monday led to three articles in the proceedings: one by L A Artsimovich, one by I N Golovin et al, and one by W D Schafranow alias V D Shafranov (presented by Artsimovich during the meeting) - all three in German, no discussions are reported. The proceedings contain an additional section with seven articles

> connected with subjects discussed at the symposium. They were not read at the conference, partly because of lack of time, and partly because some of the authors were not able to join the meetings.[34]

Four of these articles were written by three authors from the Soviet Union who were no participants of the symposium, but obviously invited for the meeting by Alfvén. In 1999 Bo Lehnert wrote a review article about his professional life, and he remembered about the Stockholm symposium:

> In August 1956 Alfvén organized a symposium [...]. Thereby Alfvén had also invited a delegation from the Soviet Union, consisting of persons nominated by him. During the day before the symposium six entirely different persons arrived in Stockholm, accompanied by a "politruk". Hannes Alfvén was confused, and his old collaborator Olle Wernholm uttered the words "What suspicious types!". However several of these "types" turned out to be the top scientists within classified fusion research in the Soviet Union, such as L A Artsimovich and I N Golovin. During the symposium they reported on high-current discharge investigations performed within the programme of the Academy of Sciences in Moscow.[35]

4.3 AERE Harwell, April 25th, 1956

Already a few months before the Stockholm symposium, in April 1956, the Soviets broke the secrecy of their classified work for the first time.

> In 1956, a Soviet delegation lead by Nikita S. Khrushchev (First Secretary of the Soviet Communist Party), Nikolai A. Bulganin (Prime Minister of the USSR) and Academician Igor V. Kurchatov (leading Soviet atomic research physicist) visited the United Kingdom in an attempt to appease the cold war. On April 25, I.V. Kurchatov read a lecture at Harwell. The Harwell site [...] was then the leading research centre of the UK's Atomic Energy Research Establishment (AERE).
>
> The lecture of Academician Kurchatov is remembered as a complete surprise with respect to its openness and deep insight into the problems of controlled thermonuclear fusion. Notice that it has even mentioned the extreme challenge of understanding the origin of measured neutrons - the

[34] Lehnert 1958, p xii, [Leh58]
[35] Lehnert 1999, p 12, [Leh99]

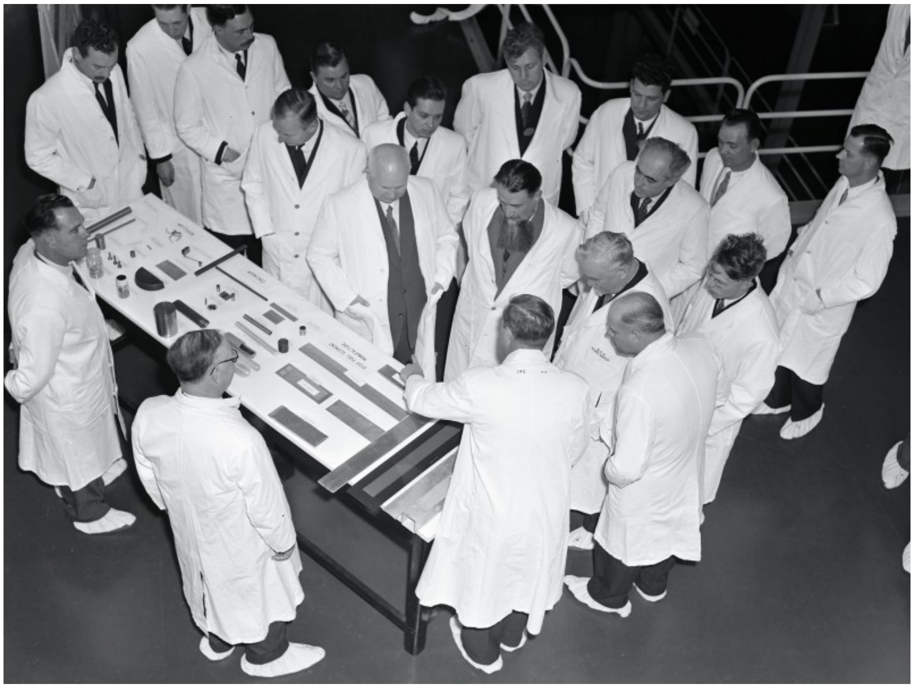

Figure 7: Igor V. Kurchatov (in the middle, with beard) during his visit at AERE Harwell, 25th April 1956. On his right is Nikita S. Khrushchev, to his left is Nikolai A. Bulganin. Opposite is Sir John D. Cockcroft, Director of AERE Harwell [Ef10, `apr05kurchatov_harwell-800x600.jpg`]

> very issue that would seriously hamper the fusion research at Harwell in 1957. [36]

The talk was given in Russian, but they brought a bi-lingual (Russian-English) report based on Kurchatov's lecture with them.[37]

> Partly under the influence of the lecture, in early 1957 the UK decided to declassify thermonuclear research, and so did the USA. The US even organised a major exhibition on their fusion research within the second UN Conference on the Peaceful Uses of Atomic Energy in Geneva in 1958. Since this conference, where fusion research had its first plenary session, there have been no veils of secrecy over our research efforts. This openness enhances our scientific horizons and enforces our trust in the potential benefits of the project. [38]

[36] EUROfusion 2010 [Ef10]

[37] Kurchatov 1956, [Kur56]. A copy is available at the Culham Library. For a while a pdf (10 MB) was available at the EUROfusion website [Ef10].

[38] EUROfusion 2010 [Ef10]

4.4 Meetings in Geneva

The political background of free international scientific exchange about atomic and nuclear physics is given in the book by David Fischer. Fischer starts around 1920 and emphasizes that the pre-war steps of research leading to nuclear power (both fusion and fission) were truly international, as we have also seen in Section 2. Fischer's book is available in full length on the web pages of the *International Atomic Energy Agency (IAEA)*.[39]

The post-war development in short: The United Nations officially came into existence in 1945. Invited by the Secretary General *Dag Hammarskjöld*, US-President *Dwight D. Eisenhower* gave a speech at the United Nations' General Assembly in Dec 1953 which was labeled later on *Atoms for Peace*. In this speech he suggested international exchange of knowledge and materials for the peaceful use of atomic energy wherever possible (agriculture, medicine, power plants etc) and suppression of nuclear proliferation, i.e. of the spread of nuclear weapons. In the following years, two *United Nations International Conferences on the Peaceful Use of Atomic Energy* re-established free international exchange of knowledge. These conferences were held in Geneva, in and near the building of the League of Nations. The first conference was in 1955 (1500 participants from many fields of science, from governments and also from the press), the second one was in 1958, September 1-13 (5000 participants).

The president of the first conference was the Indian nuclear physicist *Homi J. Bhabha (1909 - 1966)* who had studied in Cambridge (UK) and worked with several leading nuclear physicists before he returned to India in 1939. Bhabha's presidental opening address caused quite a stir:

> In his opening address [...] Indian Physicist Homi Bhabha brought fusion power to the attention of the world. Had he tossed a small A-bomb in the press section, he could scarcely have produced a greater impact than he did with his prophecy [...]
>
> From the time of Dr Bhabha's speech to the end of the conference all eyes were focussed on the possibility of hydrogen power - limitless energy from the substance of the sea. [...]
>
> Why do we never hear anything about fusion power? The answer is quite simple: secrecy. Until Dr. Bhabha's announcement at Geneva forced the Atomic Energy Commission's hand, it was not even known that the US had a thermonuclear project (later identified as Project Sherwood).[40]

Thus Dr Bhabha promoted declassification of controlled-fusion research in 1955, and the Soviets joined in with the talks at Harwell and at the Stockholm symposium. Also in 1956, the US nuclear physicist Dr Ralph E. Lapp published a detailed article in LIFE, discussing also Kurchatov's talk at Harwell and informations that he (Lapp) obtained in interviews with former Los-Alamos-colleagues at the first Geneva conference. Fusion oriented Plasma Physics was thus an important topic at the second Geneva conference

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[39] Fischer 1997 [IAEA97]

[40] R.E. Lapp 1956 [Lap56]

and was declassified then. Dr Bhabha's *famous prediction* was also cited at the second Geneva conference. He said in 1955:

> The historical period we are just entering, in which atomic energy released by the fission process will supply some of the power requirements of the world may well be regarded one day as the primitive period of the atomic age. It is well-known that atomic energy can also be obtained by a fusion process as in the hydrogen bomb, and there is no basic scientific knowledge in our possession today to show that it is impossible for us to obtain this energy from the fusion process in a controlled manner. The technical problems are formidable, but one should remember that it is not yet fifteen years since atomic energy was released in an atomic pile [reactor] for the first time by Fermi. I venture to predict that a method will be found for liberating fusion energy in a controlled manner within the next two decades. When that happens, the energy problems of the world will truly have been solved for a while, for the fuel will be as plentiful as the heavy hydrogen in the oceans.[41]

At the second Geneva meeting with its ca 5000 participants, more than 2500 papers were given, among them 109 papers on controlled thermonuclear fusion. The English edition of the proceedings gives all papers and consists of 33 volumes[42]. In addition, shortened versions of the proceedings were also published in French, Spanish and Russian. Volume 33 of the English edition consists of the index of the proceedings (210 pages) and is available in the internet. Volumes 31 and 32 deal with controlled nuclear fusion. Research on fusion in stars is dealt with in volume 30.

The first session 'Possibility of Controlled Fusion', was opened with a short introduction by the chairperson H.J. Bhabha (vol 31, pp. 39-40). Then Hannes Alfvén (vol 31, pp 3-5) discussed some basic facts about fusion research and gave a very short review of work in Sweden (to be detailed in other talks later on). Then followed a review talk on fusion research in the UK by P.C. Thonemann (vol 31, pp.34-38). Then there were two further review talks: one on fusion research in the USSR by L.A. Artsimovich, presented by E.I. Dobrokhotov (vol 31, pp.6-20), and one on fusion research in the USA by E. Teller (vol 31, pp.27-31). These two talks were followed by a lifely discussion which is also given in the proceedings. Then followed a review talk on fusion research in FRG (i.e. West-Germany) by L. Biermann (vol 31, pp.21-25).

The titles of the other sessions were 'Theoretical Aspects of Plasma Physics' (vol 31, pp 43-280), 'Experimental Aspects of Plasma Physics' (vol 31, pp 281-390), 'Controlled Fusion Devices, Part I' (vol 32, pp 3-119), 'Controlled Fusion Devices, Part II' (vol 32, pp 121-294), and 'Special Topics and Instrumentation in Fusion' (vol 32, pp 295-463). Each session had speakers from several different countries, and there was a (recorded) discussion whenever needed. Several times gladness was expressed that free cooperation is possible now, and several times it was noted that researchers in different countries got independently very similar results. In the introductory remarks of his talk *Edward Teller (1908-2003)* brought this to the point:

[41] H J Bhabha 1955, presidental address, [UNP55]

[42] United Nations Publication 58. IX. 2., 1958, [UNP58]

> It is a great pleasure to discuss with you the topic of the day and I should like to begin by expressing the same sentiments with which the previous speaker [i.e. Dobrokhotov/Artsimovich] finished his paper. It is wonderful that over a large and important area of research we can now all talk and work together freely. I hope that this spirit of cooperation will endure, that it will be generally exercised throughout the world in this field and that it will be extended also to other fields.
>
> It is remarkable how closely parallel the developments in the different countries are and this, of course, is due to the fact that we all live in the same world and obey the same laws of nature. I was particularly impressed by the wealth of detail given by the previous speaker. [. . .][43]

Other events around the same time: The *International Atomic Energy Agency (IAEA)* in Vienna was founded in 1957. Also in 1957/58, the Nuclear Energy Agency (NEA) of the OECD was established, and also EURATOM for the European Common Market (in the *Treaties of Rome*), under terms very similar to the ones of IAEA. In 1960, 'Institutes for Plasma Physics' started their work in several countries of the European Common Market, also the IPP in Garching.[44] Since then, EURATOM plays an important role for their cooperation.

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