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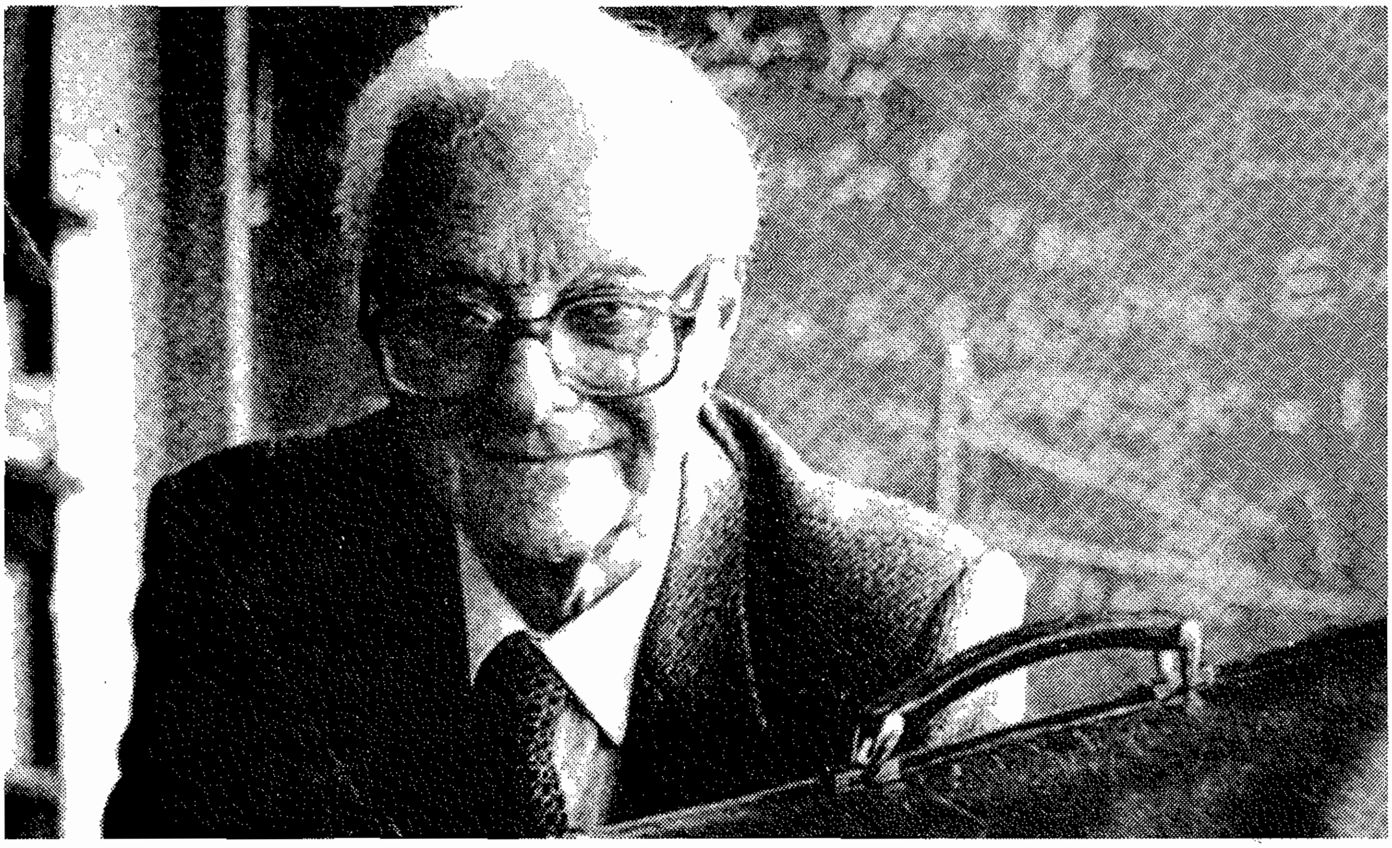

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ABSTRACT

This biography of Edoardo Amaldi (1908-1989) presents the life of one of the chief founders of CERN in its many aspects - as a physicist, an organizer, a teacher, a man of peace, and a historian. It covers his early education in engineering and physics, his research in Rome before and during the difficult war years, and afterwards, in nuclear and elementary-particle physics and later in gravitation. His major contribution to the foundation and guidance of CERN is dealt with in some detail, as well as his part in the foundation of ESRO (now ESA) and his work for the Pugwash movement and other initiatives for peace and international collaboration. Mention is made of his teaching ability and his books on scientific history. The account, originally written for the Biographical Memoirs of the Royal Society (London), includes a bibliography of all Amaldi's publications.

E. Amaldi in 1971, taken at a CERN Council Meeting

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Edoardo Amaldi died on 5 December 1989 in Rome at the age of 81. Typically Amaldi was at work; at 9.00 a.m. he had gone to the Accademia dei Lincei, of which he was the President, to give a welcome address at a scientific conference. He returned to work in his office and a little after 12 noon he had a totally unexpected heart attack in the lift of the Palazzo Corsini. He was rushed to the Santo Spirito Hospital but on arrival was found to be dead.

Only three weeks previously, on 13 November, Amaldi had been at the Inauguration Ceremony of LEP, the new electron–positron collider at the European Laboratory for Particle Physics (CERN) in Geneva, where President Mitterrand of France had acknowledged Amaldi's essential role in the rebirth of European physics in his official address. As recently as 31 October he had chaired the Conference on the Frontiers of Contemporary Physics at the Centre for Theoretical Physics at Miramare, Trieste. The week before his death he met President Gorbachev for the second time — during the Russian President's visit to the President of the Italian Republic and to the Pope — having led a delegation of Italian scientists to the International Forum organized by Gorbachev in Moscow in 1987. The energy, drive and enthusiasm that had been the hallmark of Edoardo Amaldi's life — as a physicist who had been actively involved in the most important advances in physics from 1930 onwards; as an organizer who had been the catalyst for the resurrection of European science after the Second World War; as an inspirational teacher; as a man of peace; as a historian — never left him until the moment of his death.

The early years

Edoardo Amaldi was born in Carpaneto (Piacenza) on 5 September 1908, the son of Luisa Basini and Ugo Amaldi who was successively professor of mathematics (analytic geometry, algebraic analysis and calculus) at the Universities of Cagliari, Modena, Padua and Rome. He completed his elementary studies at Modena, most of his secondary education in Padua and obtained his school-leaving certificate in Rome. The atmosphere in the Amaldi household was learned as Ugo Amaldi was close friends with several of the most influential Italian scientists and mathematicians of the time.

In the summer of 1925 the Amaldi family was on holiday in the Dolomites together with the families of other important university professors and it was here that Edoardo Amaldi first met Enrico Fermi. Fermi at that time was professor of physics at Florence and he was on a hiking holiday in the company of R.D.L. Kronig, a Dutch theoretical physicist with a particular interest in quantum mechanics. Amaldi was invited to accompany the two physicists on their walks. Although it is probably fair to say that much of the older men's conversation went far over Edoardo Amaldi's head, it was at this point that his interest in physics first germinated. Later during the same holiday Fermi and Amaldi spent several days together on a bicycle tour and a close friendship was established between the two men well before Amaldi had seriously considered becoming a physicist.

In 1925, at the age of 17, he enrolled in the first two-year cycle of the full five-year engineering course in Rome despite his already considerable interest in physics. In 1927 Senator Orso Mario Corbino, professor of experimental physics and Director of the Institute of Physics, who was the elder statesman of Italian physics at the time, had been successful in luring Enrico Fermi from Florence to take up the recently instituted chair of theoretical physics in Rome. Towards the end of the second year of Amaldi's engineering course, Corbino, who was convinced that physics was about to undergo a fantastic development, made an appeal to the young engineering students urging them to change the course of their study and join the Faculty of Physics. Amaldi immediately followed this advice and transferred to the Institute of Physics. When he entered the Institute, Amaldi thus found himself under the direct leadership of Enrico Fermi and Franco Rasetti who had followed Fermi from Florence to Rome and had become Corbino's assistant. Rasetti's experimental abilities complemented Fermi's teaching to an extraordinary degree, as at the time the latter was mainly concerned with theoretical physics.

After transferring from engineering to physics, Amaldi found himself in the company of Emilio Segré who was about three years his senior. The two young men had recently met for the first time during a short climbing holiday on the Gran Sasso and had become good friends, a friendship reinforced by the fact that Segré, in fulfilment of a long-held desire, had just left the School of Applied Engineering to pursue physics studies. At university Amaldi attended the lectures of many famous teachers including Guido Castelnuovo, Tullio Levi-Civita, Vito Volterra, Enrico Fermi and Franco Rasetti.

He began work on spectroscopy in 1928, though he had already begun to publish when he was 20. Segré said of him (in ref. [1], Perspectives, p. 355):

> *'When Amaldi joined physics from engineering in 1927, he was the youngest. He had a rosy complexion and looked even younger than his age. This earned him the sobriquet "Fanciulletto" ("the kid"). However, as a result of his sporting activity, he was also known at that time as "Adonis".'*

Amaldi obtained his Laurea (doctorate) in July 1929 with a thesis on the Raman spectrum in the benzene molecule [2], which was supervised by Rasetti. Ettore Majorana, who had followed Segré's example and transferred a year or so later from engineering to physics, and Gabriello Giannini, who years later was to become a well-known industrialist in the United States, both graduated the same day.

Edoardo Amaldi, Franco Rasetti and Emilio Segré in 1928

At the beginning of 1931, after military service, Amaldi went to Leipzig on a scholarship from the Opera Alberoni in Piacenza to work for about ten months under Peter Debye on the diffraction of X-rays by liquids [4]. Amaldi had already distinguished himself by his original work as a physicist, with publications on atomic and nuclear spectroscopy. These particularly showed his independence as a theorist and his skills in the use of mathematics [1, 3].

This period in Leipzig most probably had an important formative effect on the young scientist. At the age of 23 he was experiencing the benefits of international collaboration in science and this undoubtedly played a decisive role in shaping the mind of Amaldi and explains many subsequent actions in his fight to avoid "provincialism" of national research.

Shortly after returning to Italy he became Corbino's assistant and resumed his work in the spectroscopy field. Among his research in molecular spectroscopy, mention must be made of the study of the Raman rotational spectrum of ammonia (1932) in collaboration with G. Placzek [7, 9], the first experimental proof of the corresponding selection rules calculated for the 'symmetrical top rotator' with wave mechanics which had recently been described by G. Placzek and E. Teller.

Among the works on spectroscopy, those dating to 1932–34 [8–12] (some in collaboration with Emilio Segré) are of particular interest. They stemmed from a study of the high terms in alkaline metals subjected to an external electric field. He was able to show the contribution of quadratic terms in the Stark–Lo Surdo effect, but soon a new effect was discovered: a considerable displacement of the elastic terms of the absorption series in alkaline vapours, when the latter is contained in an extraneous gas (argon for example). The authors dubbed the atoms in this situation "swollen atoms" (nowadays they are known as Rydberg atoms), because the electron orbits were very large and could incorporate hundreds of extraneous atoms. These atoms displayed very interesting properties, since the orbital energy was slightly altered by the presence of extraneous gases; Fermi developed a theory of the phenomenon where he first introduced the notion of 'scattering length'. For many months Amaldi studied such unusual broad orbits in detail [15, 23].

Nuclear research in via Panisperna

But by the early nineteen-thirties, Amaldi and the School of Rome had already begun to feel that the centre of physics interest was shifting from the atom towards the atomic nucleus. In an inspired speech at this time Corbino said (Segré, op. cit., p. 358) :

> *"The only possibility of major new discoveries is by successfully attacking the atomic nucleus. This is the really worthy objective of future physics."*

These were prophetic words which meant entry into a new field, with new experiments, and above all a new grounding in theory. Amaldi made contact with the Cavendish Laboratory in Britain, which he visited with Segré in 1934. Rasetti went to work with Lise Meitner in Berlin on the study of new nuclear techniques. Segré went to Otto Stern in Hamburg.

Beginning in 1932, as part of the new approach of the Rome Institute, Amaldi devoted his energies to the study of nuclear physics. Thus began his famous collaboration with Fermi, Segré, d'Agostino and, a few years later, with Pontecorvo. To Amaldi is due credit for arranging and being the main contributor to an important seminar held regularly in the Physics Institute where the Rome group made a detailed study of Rutherford, Chadwick and Ellis' work, and their famous book "Radiations from radioactive substances".

The experimental work of the Institute in via Panisperna, following the discovery made by Joliot-Curie of radioactivity produced by alpha particles, was devoted to analysing what happens when the atomic nucleus is bombarded by neutrons [13, 14] and lasted from 1933–34 to 1938. It was also during this immensely creative period that Amaldi found time to complete his scientific education at the Cavendish Laboratory in Cambridge in the summer of 1934; at Columbia University and at the Department of Terrestrial Magnetism at the Carnegie Institution in Washington D.C. in the summer of 1936.

Studies with neutrons for bombardment led to the discovery of many new radioactive nuclei distributed through Mendeleev's periodic table of elements, from the lightest elements to thorium and uranium.

But the greatest discovery was the slowing down of neutrons, and of their highly unexpected properties. Among the outstanding experimental results of these studies we should note [16–22, 24–27]: the effect of the chemical bond of atoms in the moderator on the elastic cross-section of neutrons; experimental identification of the disintegration process induced by slow neutrons in boron; verification of the existence of resonances in neutron capture in nuclei, and the first determination of the width of the corresponding levels. To this period can also be dated the complete study of neutron slow-down and scattering.

The study of slow neutrons began with the work "Azione di sostanze idrogenate sulla radioattività provocata da neutroni" (the action of hydrogenated substances on radioactivity induced by neutrons) [19], and continued to Amaldi's and Fermi's masterly summaries of work done, published in Phys. Rev. [28,29,32–36].

There is no better way to understand the atmosphere and excitement in via Panisperna than by using Edoardo Amaldi's own words on how slowing-down was discovered. The passage is taken from his "Personal Notes on Neutron Work in Rome and Post-War European Collaboration in High Energy Physics" [130].

"In those weeks some strange results were obtained on the intensity of irradiation by neutrons, which seemed bizarrely to depend on the experimental positioning of the source. It was therefore decided to try and establish a quantitative scale of activity induced by neutrons. This work was entrusted to me and Bruno Pontecorvo, who had graduated in 1934. (Pontecorvo had just completed his university studies and was to distinguish himself in the field of neutrinos.)

We began by studying the most suitable irradiation conditions for obtaining easily reproducible results. The activity of silver, with a half-life of 2.3 minutes, was chosen as indicator. But we found ourselves in immediate difficulties because it transpired that the intensity of activation depended on the mode and position in which irradiation occurred. In particular, there were some wooden tables near a spectroscope in the dark-room which displayed miraculous properties: for one and the same neutron dose from the source the silver on these tables was much more activated than if it had been irradiated on a marble table in the same room.

To clarify the situation I began a systematic investigation (N.B. this is where the discovery began); it is documented in notebook B1 where our measurements were noted down. They began on 18 October 1934."

The neutron source (Rn + Be) was in fixed position; the measurements were made by placing the silver cylinder that had been irradiated at an equal distance from the source inside and outside the container. The results show that activation decreases with distance from the source, more slowly inside than outside the container. This was therefore a clear indication that; the absorption in lead was more or less compensated for by diffusion in re-entry by neutrons leaving the source in directions other than that of the detector. It was decided to test this conclusion with a better design geometry.

"On the morning of 22 October nearly all of us were involved in examinations and Fermi decided to carry on the measurements on his own. Bruno Rossi from Padua and Enrico Persico from Turin happened to be at the Institute in Via Panisperna. Persico was, I believe, the sole witness to what took place. When he was just about to insert a lead wedge, Fermi decided "on the spur of the moment" to try a lighter element, and initially used paraffin... At midday on 22 October we were all called in to see the extraordinary effect of filtration through paraffin: activity increased by an appreciable factor.

As usual, work broke off shortly before 1 o'clock and resumed at three. But in the meantime Fermi had worked out an explanation for the strange behaviour of the filtered neutrons: they were being slowed down by elastic collisions with the protons in the paraffin, thereby being made more efficient; i.e. the probability of their being captured by the silver increased. In those days, it should be noted, the increase in cross-section in reaction to a reduction in neutron velocity was unexpected and was actually against all current theoretical predictions.

The same afternoon we repeated the experiment using the pond in the garden of the Institute. In this way were clarified the earlier experiments and those of Fermi. Fermi continued with the hypothesis that the neutrons could be thermalized and the same day he proposed an experiment to verify the hypothesis".

Amaldi continues : *"The evening of 22 October, the whole group came to my house and we wrote a scientific letter to "Ricerca Scientifica"* [19]. The article was signed by Enrico Fermi, Edoardo Amaldi, Bruno Pontecorvo, Franco Rasetti and Emilio Segré.

Ginestra Amaldi's memory is that the following day Livia, who worked for the Amaldis as home help, asked her whether the gentlemen had been drinking the previous evening, so excited and noisy had they been.

Edoardo Amaldi, Bruno Pontecorvo, Franco Rasetti and Emilio Segré were all under 30 years old and Fermi was still only 33. How many after-dinner sessions were more important to the history of this century than that celebration held in the Amaldi household, with the eldest among them a man of 33? At the time, the tradition of research was still generally an individualistic enterprise. However, Fermi, Rasetti, Segré, Pontecorvo and Amaldi were to become world famous as the "Group of Rome". Here was a group, publishing as such and known as such; indeed much later the Harvard historian G. Holten wrote a study on this way of doing physics. This was a novelty, and it can well be imagined that the lesson of its effectiveness was not lost when Amaldi, twenty years later, was to organize the style of work in the nascent CERN laboratory. The group stuck together, not only in their professional lifes but also socially, particularly in sports: with their families they would play tennis regularly (Pontecorvo was a champion) and go to the mountains to climb and ski. Edoardo Amaldi was a particularly skilled climber, often leading the way on grade 5 climbs in the Dolomites. He continued to climb well into his sixties. The importance of sport to Amaldi is clear from his letters to Enrico Fermi after the war in which, apart from physics, there was much discussion on how to procure tennis balls which could not be found in Italy at that time! Well into his seventies Amaldi ran 5 km every morning; he was only satisfied when the time was less than twice that of the world record.

The discovery of the effect of hydrogen on the radioactivity induced by neutrons obviously changed the interests and lifestyle of the members of the group, then that of their families. Eventually, in the space of a few years, it changed the face of the world and could be considered as one of the most important and far-reaching scientific discoveries of the century.

In September 1984 an issue of the Journal Physics Reports came out with the title "From the discovery of the neutron to the discovery of nuclear fission" [163], in which Amaldi covered ten years of history in 350 pages including over a thousand references. Those who have read it are plunged back into the feverish atmosphere of the times, when something new was happening every day. In four years Amaldi was involved in the discovery of more than fifty radioisotopes; and world-wide recognition came to him.

In 1937 Amaldi took part in the national competition for the chair of Experimental Physics of the University of Cagliari and was placed first by the selection committee. But just afterwards Corbino died prematurely and Amaldi was called to the chair of Experimental Physics of the University of Rome. He held this post for a remarkable period of 41 years.

The war years

The axe finally fell on the "Group of Rome" in the form of the "racial laws" promulgated by the Fascist government on 14 July 1938. Fermi's wife, Laura Capon, and their children were hit by these laws — Laura's father, an Admiral in the Italian navy, being Jewish — and so Fermi and his family decided to leave in December 1938. Their first stop on the voyage to the United States was Stockholm where Fermi received the Nobel Prize for Physics for "*... his identification of new radioactive elements produced by neutron bombardment and his discovery, made in connection with this work, of nuclear reactions effected by slow neutrons*". The importance of the research of the "Group of Rome" had gained the highest international recognition. Segré, who was temporarily working in Berkeley, decided, as a result of the political situation in Italy and Europe, to stay, and his wife, Elfriede, and their two-year-old son Claudio left Italy to go back to Berkeley. Bruno Pontecorvo had left some time before to work with Joliot-Curie in Paris, and Rasetti left in the summer of 1939 to take up a post as Professor of Physics at Laval University Quebec. Of the "Group of Rome" only Amaldi was left.

Amaldi himself had in fact gone to America with Franco Rasetti in 1939 and was offered work in several Universities. However, knowing that he was not forced to leave Italy, and would be taking a position which another scientist who had been obliged to leave Europe might take, he decided to return to Rome in October 1939. In May 1940 Amaldi was mobilized in the Italian Army and sent to North Africa. Happily, six months later, at the request of the Faculty of Sciences of Rome he was recalled to his teaching position.

In 1937, Amaldi, Fermi and Rasetti had built their first neutron generator at the Rome Institute of Physics. Based on a 200 000 Volt Cockcroft–Walton and a tube for accelerating protons and deuterons, it was a model for a later system, designed to operate at higher energies. Amaldi had gained practical experience in designing and operating such machines during his visit to Columbia University and at the Department of Terrestrial Magnetism at the Carnegie Institution in Washington D.C. in the summer of 1936 [40].

The definitive version, designed by Amaldi, was built the following year by Amaldi, Fermi and Rasetti with a grant from the Italian National Research Council, Consiglio Nazionale delle Ricerche (CNR), at the then Institute of Public Health's Physics Laboratory (Istituto superiore di Sanità), working in collaboration with physicists on the latter's staff [46, 53]. It was completed and began operating between the end of 1938 and the beginning of 1939, when Fermi had already quit Italy. Several experimental results, treasures of ingenuity, obtained in difficult wartime conditions deserve our admiration.

E. Amaldi on military service in Rumie, Libya, July 1940

On this 1 MeV generator a series of investigations were carried out in collaboration with Daria Bocciarelli, Franco Rasetti, Guilio Cesare Trabacchi and subsequently Mario Ageno who had graduated in 1936 under Fermi [47–52]. The main research included the study of neutron–proton and neutron–deuteron collisions, chosen as the least indirect way of obtaining information on the forces acting between nucleons.

For neutron-proton collisions, Fermi and Amaldi had already determined cross-sections for incident neutrons with energies of a few eV [33, 36]. Amaldi and his co-workers measured the neutron-proton cross-section at 0.2–0.3 MeV with neutrons produced in the reaction $^{12}C + ^{2}D \longrightarrow ^{13}N + ^{1}n$. Then neutron–proton and neutron–deuteron collisions were studied using a new method, with three proportional counters mounted in series to determine the angular distribution of recoil protons from normal, and heavy paraffin targets, bombarded by neutrons of energies between 12.5 and 15 MeV [49, 54, 57, 58, 61, 62, 64, 70].

From 1939 to 1941 the group worked on uranium fission [50, 51, 55], particularly on the increased cross-section of ^{238}U, in which the energy of the incident neutron is close to or larger than 20 MeV. The theory of this effect was set out by Niels Bohr and John Wheeler in a scientific note printed in the Physical Review in 1939. The implications of the work on uranium were clear and Amaldi looked back to this period during a colloquium in 1982. (Journal de Physique, Dec. 1982).

"We found an interesting increase in the cross-section and together with Gian Carlo Wick — our theoretician — I corresponded with Niels Bohr (in Copenhagen) who suggested a transparent interpretation of our results.

When we understood that the United States were close to entering the war, we summarized our results in a paper written in English [58] and sent it to Physical Review, where it appeared after the Japanese attack on Pearl Harbour.

At that time we held a small meeting (G. Bernardini, B.N. Cacciapuoti, B. Ferretti, G.C. Wick, E. Amaldi and a few others) in which we decided to stop any work on fission and to employ our limited manpower in completely different problems.

The reason for such a decision was that we had arrived at a conviction that almost any problem related to the investigation of fission could become of interest for the construction of weapons and we did not want to become involved in this kind of work.

The first years after the end of the war were times of intense activity around the 1 MeV accelerator.

A series of experiments were concerned with the elastic scattering of fast neutrons by medium and heavy nuclei. The aim of these studies was to compare, for the same nucleus and for neutrons of well-defined energy, the two cross-sections for formation of the compound nucleus and for coherent scattering of incident neutrons, in order to verify experimentally the theory predicting that the latter would have value double that of the former. The authors also sought to show diffraction effects in the angular distribution of neutrons elastically scattered from nuclei. This was the most direct measurement made hitherto of nucleus size and diffraction phenomena, at wavelengths a factor of a thousand lower than had been previously observed [65, 68a, 71a, 71b, 72].

There proved to be good agreement with theory and the radius of the nucleus could be measured as a function of its mass. These measurements were the first clear experimental test of the so-called "optical theorem". The scientific significance was immediate and great: its universality is due to the fact that it is a direct and clear consequence of the diffraction of fast neutrons when they are scattered from nuclei.

From the years of reconstruction in Italy to the birth of CERN

Italy emerged from the war years in a state of chaos and it is during this period that Edoardo Amaldi's talents for organization and for motivation played an extremely important role in the rebuilding of Italian physics and ultimately in the re-emergence of Europe as a leader in physics research. This was an extremely busy and creative period for Amaldi. He was occupied simultaneously with his own scientific research, with the rebuilding of research and physics studies in Italy, and with the revival of European physics, including the mighty enterprise that is CERN (the European Council for Nuclear Research). It is safe to say that all physicists working in Europe today owe a debt to Amaldi. His drive and energy laid the foundations for the great advances made by European physics in the post-war period.

However, let us return to Rome University where Amaldi was working and teaching whilst in parallel doing experiments with the accelerator of the Istituto di Sanità across the road. The Physics department having moved in the summer of 1936, from the old Institute of via Panisperna to the present site in the Città Universitaria "La Sapienza", the group remaining around Amaldi at the Institute Guglielmo Marconi consisted of Bruno Ferretti, Oreste Piccioni, who had only just graduated, and a very talented student, Marcello Conversi. Antonino Lo Surdo was Director of the Institute.

The group was joined, initially on a part-time basis and later full-time, by various other physicists soon to be of note such as Gilberto Bernardini, Gian Carlo Wick and, for short periods, Giuseppe Cocconi. Then there was Giovannino Gentile, a young theoretical physicist who died in 1941, Piero Caldirola and Antonino Borsellino. In 1940 Cacciapuoti joined from Palermo and Pancini from Padua.

The scientific activities during the period 1938–45 have already been mentioned but it is worth while giving some details of the working conditions in Rome during the war years. This information comes from Amaldi's own excellent history of the period "The Years of Reconstruction" [148].

The Institute was bombed on 19 July 1943, but the counters and electronics from the — as yet poorly known — experiments of Conversi and Piccioni were salvaged. Says Amaldi:

> *"The counters and the electronics of this experiment had been taken away from the Institute a few days after the first bombardment of Rome by the American Air Force. The goal of the incursion had been the goods station San Lorenzo, but more than eighty bombs had fallen within the perimeter of the Città Universitaria, damaging various buildings. It was the 19th of July 1943. I remember that I was with Gian Carlo Wick in my office when we heard the air-raid warning and that while we were moving rapidly towards the stairs to reach the basement, we clearly saw through the windows the bombs falling on the Chemistry building in front of our Institute. All the window glasses of our building had gone, but the structure had not been damaged.*

We were afraid however, that other bombings could follow the first one, making the continuation of the work impossible. For various reasons, the interruption was by now unavoidable for all researches except for the measurements of Conversi and Piccioni, whose experimental set-up with some spare electronic material, formed in that moment a kind of little closed system.

It was necessary to find a place sufficiently close to the Vatican City, to be within an area reasonably protected from the air-raids. These conditions appeared to be fulfilled by the "Liceo-Virgilio", ... it (the equipment) was transported there towards the end of July 1943 by a hand cart.

I remember that besides Piccioni there were three new students: C. Franzinetti, F. Lepri and L. Mezzetti. I accompanied them along via Nazionale and corso Vittorio Emanuele on my bicycle. Sometimes I preceded, sometimes I followed the cart trying to avoid road accidents and asking the policemen to give us the right of way.

Immediately after the arrival of the Allies, we also brought back to the Institute from the Liceo Virgilio the equipment that Conversi and Piccioni had built and used for measuring the mean life of mesons. The measurements had been carried on almost without interruption also during the months of occupation. To keep this experiment in operation, at any cost, had become, for all of us, a kind of symbol of our will of cultural and scientific continuity."

With the arrival of Allied forces on 5 June 1944 the Institute resumed its activities on a more intense footing. The instruments were reassembled, and teaching and research was set in motion again at a pace and degree of effort that was extraordinary. The frantic desire to start experimentation again is well illustrated by this passage from Amaldi's "Years of Reconstruction":

"The continuation and development of our work was made possible by using materials acquired from the camps of A.R.A.R. (Azienda Rilievo e Alienazione Residuati) where the residual war materials had been collected. A few of our young people had specialized in this type of recovery operation which sometimes was rather adventurous. Once S. Sciuti and F. Lepri, another time Pancini and Quercia, brought to the Institute from a camp near Capua a truck of electrical (oscilloscopes, amplifiers) and optical (cameras, theodolites, etc.) materials.

The fact that we had at our disposal for the first time, thanks to those expeditions, hundreds of electronics tubes of well-defined types, had also a considerable influence on our approach to the planning and designing of new experimental setups, in which soon we started to include, for example, even counters hodoscope of large dimensions."

There were roughly two main research areas at that time in the Marconi Institute: cosmic rays, which Gilberto Bernardini was mainly responsible for, and nuclear research, which Amaldi was entrusted with. From then on Amaldi and Bernardini became the main fulcrums of Italian physics and soon had clear-cut national and European responsibilities.

The National Research Council was reopened and reorganized with Gustavo Colonnetti at its head. In 1945 a Centre for Nuclear Physics and Elementary Particles (Centro di Studio della Fisica Nucleare e delle Particelle Elementari) was set up at the Istituto di Fisica Gugliemo Marconi, whose Director and Vice-Director were Amaldi and Bernardini respectively.

Later that year Amaldi attended a conference in Como:

"We reached our destination after a 36-hour trip with our rucksacks full of supplies, having crossed on foot pontoon bridges over a few rivers, on the banks of which the trains mainly composed of cattle carriages stopped. This was the first reunion of the physicists of Central and South Italy with those of North Italy".

Italy's wounds were on the mend. Albeit not alone, but as the main protagonist, Amaldi had succeeded in saving the School of Rome and the work of the Rome Institute of Physics in the years 1940–45, with the result that great discoveries were still possible. He lent it a rhythm and pace of work that moved inexorably forward: producing new instrumentation, inventing, imitating, working on new machines and with new criteria.

In 1946 Bolla, Salvetti, Salvini, Silvestri in Milan decided to study nuclear energy and design a nuclear reactor for peaceful purposes. They discussed this idea with Amaldi who was supportive from the outset. The Centro Italiano di Studi ed Esperienze (CISE, the Italian Centre for Studies and Experiments) was founded, in collaboration with Amaldi and Bernardini, and soon had the support of Northern industry. CISE would be devoted to applied nuclear research, and would collaborate closely with the Rome Institute.

In 1948 Amaldi was elected Vice-President of IUPAP (International Union of Pure and Applied Physics). In June 1952 he was nominated as a member of the Comitato Nazionale per le Ricerche Nucleari (CNRN).

During the immediate post-war period Amaldi travelled to Cambridge in July 1946 to give a talk on the work at Rome during the conference on "Fundamental Particles and Low Temperatures". Here he met John Cockcroft whom he knew from his first visit to the Cavendish Laboratory in 1934. Amaldi said of this meeting,

> *"This short renewal of contact and his unexpected interest for physics in Italy, were for me indications of the possibility of initiatives on a European scale that I had not yet imagined".*

This visit planted the first seed of the enterprise that was to become CERN.

The Amaldi family at the "Poggio", the house in which Edoardo Amaldi was born (Carpaneto, Piacenza), 1948 From left to right, Ugo, Ginestra, Francesco, Daniela and Edoardo Amaldi.

In the same year (1946) Amaldi also travelled to the United States where Fermi offered him a chair at the University of Chicago. Amaldi comments:

> *"The offer was so agreeable and attractive as to strongly shake my intention of staying in Italy, but I felt a certain responsibility towards the younger researchers and the duty of contributing to the reconstruction in the changed political climate. In rapidly taking a final decision to return to Italy an important influence was the clear, although unexpressed position of Ginestra (Amaldi's wife), who accompanied me on the trip, and had no doubt about my duties and tasks in our country of origin."*

It was natural for Italy's direct interests to extend towards Europe and vice-versa. Work on the Frascati synchrotron began in 1953 and was completed in 1959. The 1100 MeV electronsynchrotron was proposed by Bernardini, and Amaldi immediately argued for it, considering it timely and useful. Much of the Italian accelerator's success is due to the common action of the two founding fathers and to Giorgio Salvini, who was its inspired director. In the mean time the Italian National Institute of Nuclear Physics (INFN) had been founded in 1952 with Amaldi as its first president. In 1952 he set up and became Director of the School of Advanced Nuclear Physics Studies at the University of Rome, a post he held until the end of the 1965–1966 academic year.

Amaldi's next successful goal was Europe. As he said :

"The idea of a broad European collaboration to produce an accelerator that no single European country could build on its own became an overriding aim in the various countries, institutes and universities from 1948 onwards."

Photo of E. Amaldi taken just after the War.

Not least in Rome, where the prehistory of the future CERN began. And so we arrive at the origins of CERN, which so strongly bears the stamp of Amaldi if not his signature.

Edoardo Amaldi and CERN

Surely the greatest monument to Edoardo Amaldi's work is CERN (the European Laboratory for Particle Physics). CERN has developed into the largest physics research centre in the world, where approximately 50% of the planet's particle physicists work. Amaldi's dream of re-establishing a centre of excellence in Europe and of stopping the 'brain drain' to the United States has been fully realized and a full examination of his role in the setting up of the Organization is, I believe, justified.

Towards the end of the 1940s a number of science administrators and physicists, including Edoardo Amaldi, began to think on how best to rebuild nuclear physics in Europe.

It was clear that a co-operative effort was needed. True, both Britain and France had launched national accelerator and research reactor construction programmes immediately after the war. But their efforts were dwarfed by developments across the Atlantic: the newly established Brookhaven National Laboratory (BNL) on Long Island planned to have a range of nuclear facilities, including a 3 GeV proton synchrotron (the Cosmotron), and an even bigger machine was arranged for the Berkeley Radiation Laboratory now known as the Lawrence Berkeley Laboratory. These were far more powerful than anything envisaged in Europe.

To compete, European nations would have to collaborate.

An important step towards this goal was taken at the fifth General Conference of UNESCO held in Florence in June 1950. Isidore I. Rabi, Nobel prize-winner and a founder of BNL, was a member of the American delegation to the meeting. Frustrated by the lack of constructive proposals on the programme, he drafted a resolution after lengthy discussions with Amaldi and other scientists, notably Pierre Auger, who was UNESCO's Director for Exact and Natural Sciences at the time. The resolution asked the Director-General *"to assist and encourage the formation and organization of regional research centres and laboratories"*. Although not mentioned in the resolution, in discussions Rabi made it clear that he thought that inter-European collaboration in the field of physics would be particularly suitable.

Rabi's resolution was important, if only because it indicated that the Europeans could count on American support in the nuclear field. Two men immediately took up his suggestion: Pierre Auger and Edoardo Amaldi. Arriving in the United States early in July, Amaldi met several friends and colleagues including Bernardini, Rossi, Pontecorvo, Weisskopf. He also visited BNL. His diary captures the impression the still unfinished Cosmotron made on him: *"Passo la giornata a visitare Brookhaven. Colossale!"*. Participating in the meeting of the IUPAP Executive Committee held at Cambridge (Mass.) on 7 and 8 September 1950, Amaldi suggested that the body should consider how best to implement the Florence resolution. The Committee decided that Rabi should be invited to spell out his ideas more clearly, and that Amaldi should *"contact European physicists, in order to reach agreement on several basic issues, if possible"*.

Back in Europe, Amaldi wrote to Auger on 3 October 1950 with a view to starting *"some form of collaboration"*. He was particularly concerned to co-ordinate the action of IUPAP and UNESCO so as to ensure that a single programme was put forward, detailing the location, management, and funding of a possible European laboratory. Amaldi had been disappointed by the somewhat lukewarm reception of his ideas at the IUPAP meeting, and he felt that if he and Auger were not careful *"the sceptics (would) kill the thing before it (was) born"*.

Auger shared Amaldi's determination to push forward the European laboratory project with the greatest possible haste. On 12 December 1950 he convened a meeting of important physicists and science administrators at the Centre Européen de la Culture in Geneva. Edoardo Amaldi and Gustavo Colonnetti, the President of the Consiglio Nazionale delle Ricerche from 1944–56, were invited from Italy. The meeting resolved that Europe build a laboratory equipped with an accelerator more powerful than anything envisaged in the world, i.e. than the 3 GeV Cosmotron at Brookhaven or the 6 GeV Berkeley Bevatron. It also proposed that a study office be created immediately in Paris in liaison with UNESCO.

Within a week Colonnetti had arranged for an advance of 2 million lire from the Italian CNR for preparatory studies on the project. Additional contributions from Belgium and France followed shortly thereafter.

As matters turned out the study office never materialized, primarily because suitable competent staff for it could not be found. Instead Auger, after consultation with Amaldi — whom he regarded as a *"superconsultant on the physics side"* — decided to call a meeting of experts to spell out the European laboratory project in more detail. These experts, Alfvén (SE), Amaldi (IT), Capon (BE), Dahl (NO), Goward (GB), Heyn (NL), Kowarski and Perrin (FR) and Preiswerk (CH), met at UNESCO headquarters in Paris from 23–25 May 1951. Their official report gave some of the reasons justifying a collaborative European project — the cost exceeded that which any single country alone could afford, without such a facility there would be brain drain of European physicists to the US ... — proposed that the laboratory be equipped with a 3–6 GeV accelerator, and estimated that it would take five years and $20–25 million to build. The experts also proposed that an intergovernmental conference be called, and that it be asked to set up a provisional organization endowed with $200,000. This was the money needed to go ahead with the technical design of the accelerator while the administrative and legal aspects of the project were being worked out by the participating states.

The intergovernmental conference duly met under the auspices of UNESCO on 17–20 December 1951; a cloud hung over its deliberations. During the summer the "sceptics" grew increasingly wary of the developments being spearheaded by Auger and Amaldi. More specifically Bohr, Chadwick and Kramers, some of the most eminent members of the European physics establishment, questioned the practicality of starting a new laboratory from scratch, and feared that it could only drain already scarce resources away from national scientific efforts. As an alternative Kramers and Chadwick suggested that any new laboratory be organically linked to an existing establishment — specifically, to Bohr's institute in Copenhagen — and that it start by building a relatively modest accelerator. The UNESCO consultants, including Amaldi, were not to be deflected from their path, and a meeting in October and November 1951 absorbed the opposition's ideas in a modified version of their own project. This formed the basis of the compromise adopted by the government representatives at a reconvened conference in February 1952, and a provisional "Council of Representatives of European States for planning an International Laboratory and other Forms of Co-operation in Nuclear Research" met for the first time in Paris on 5 May 1952. Six weeks later it simplified its name to the European Council for Nuclear Research, abbreviated CERN (from the French equivalent).

The significance of Amaldi's contribution to these events, and the esteem in which his colleagues held him, is apparent from their reaction to his being initially excluded from the official Italian delegation (Casati and Colonnetti) to the first intergovernmental conference. Apparently de Clementi, Italy's permanent delegate to UNESCO, bore a political grudge against the scientist. This was something many European scientists and Colonnetti himself could not accept, and after getting in touch with Amaldi several times on the first afternoon, arranged for him to arrive with several delegates that evening. The next day Edoardo Amaldi attended the conference, and was greeted enthusiastically by Sir George Thomson, the British delegate — and there the matter rested.

One of the first tasks of the Provisional Council was to nominate the heads of the four study groups whose job it was to design the new laboratory and its facilities, and a Secretary-General to take overall responsibility for the project. Dahl and Bakker were respectively asked to lead the Cosmotron Group and the Synchro-cyclotron Group, Bohr was made responsible for Theoretical Studies, and Kowarski was put in charge of the Laboratory Group, which dealt with the site and buildings. Edoardo Amaldi was appointed Secretary-General; he held this post from 1952 to 1955 and as such he oversaw the planning and the beginnings of construction of the Geneva Laboratories.

Organizationally the role was an onerous one, lightened only by the enthusiasm, the spirit of adventure, and the determination to succeed which imbued all the participants. The group leaders remained at their home stations for most of the life of the provisional CERN, Amaldi in Rome, Bakker in Amsterdam, Bohr in Copenhagen, Dahl in Bergen, and Kowarski in Paris. As co-ordinator of their activities, Amaldi instituted a system of Weekly Reports detailing all the activities at the Rome office so as to keep them in touch with each other and with more general developments.

As Council Secretary he played an important role in preparing the two reports to Member States on the financial and organizational implications of setting up a European high energy physics centre, essential documents in the national decision-making processes. And as the organizational lynchpin and determined protagonist of the new venture, Amaldi was ever ready to advise (and, if necessary, pressure) governments to join in the envisaged laboratory.

Amaldi played a particularly important role in dispelling the last doubts on membership of a somewhat reluctant British government. At the end of 1952 the Department of Scientific and Industrial Research was still not sure that it was really interested in the European project. It decided to invite Amaldi to London and to ask his opinion *"about how far we can hope to get the benefits of the Centre with the least possible liability,"* ..... *"by which, in fact, we meant that we did not want to contribute to the cost of the 600 MeV machine"*. (The quotations are from memoranda written on 11.12.52 and 12.12.52 by H. Verry in which he described what transpired at the meetings between DSIR officials and Amaldi.) This was the smaller of the two accelerators planned for CERN, and one which some people in Britain felt was "redundant" for them, given the relatively comprehensive range of national accelerators that were just coming on-stream. Amaldi strongly opposed any idea that the UK could contract out of parts of the European Laboratory project. He also had a stormy meeting with Lord Cherwell, which apparently opened with Cherwell, who was Prime Minister Churchill's close confident on scientific matters, provoking his visitor. The new laboratory, said Cherwell, seemed to be just another international organization which would cost a lot of money and produce a lot of paper of no practical use.

Amaldi fought back, explaining why he thought Cherwell was wrong. About a fortnight later the British government officially announced its intention to join CERN.

One of the important tasks of the Provisional Council was to find a suitable man to be CERN's first Director-General. Edoardo Amaldi was one of the first potential candidates to be approached. He turned down the offer for two main reasons. Firstly, he wanted to put an end to the suspicion, apparently particularly strong among the Scandinavian Council delegates, that he and some of the other group leaders were motivated primarily by personal ambition, and that they were seeking to gain control of European physics and to secure their own positions in the new laboratory. Secondly, he wanted to return to an active scientific life. In fact despite a heavy organizational load he managed to persuade the Council to "sponsor" two cosmic-ray expeditions in the Mediterranean, and personally reported on their findings. Hence at the Council session in October 1953 Amaldi publicly stated that he would no longer be available to the organization once the Convention came into force.

Within six months the Provisional Council unanimously recommended that he be appointed the deputy Director-General of the "permanent" CERN. This was because the so-called Nominations Committee's preferred candidate for Director-General, Felix Bloch, was only willing to take on the post if he were left more or less completely free to pursue his scientific interests, unimpeded by machine building or administration. Bloch, a European refugee and Professor at Stanford University, had recently won a Nobel prize for his work on nuclear magnetic resonance, and the Nominations Committee felt that his scientific eminence — and the fact that he would be drawn back to Europe — were just the kind of qualities CERN's first Director-General should have. Accordingly, Amaldi was begged, even implored, to accept the post of Bloch's Deputy, with prime responsibility for organizational and administrative matters, which he accepted. However, this situation was far from ideal and did not last: Amaldi was Vice-Director from September 1954 to February 1955. Bloch resigned immediately afterwards and Cornelius Bakker — who many, Amaldi included, had thought would have been a more suitable director for the new organization — was appointed.

VI Session of the provisional CERN Council, (from left to right) Pierre Auger, Lew Kowarski and Edoardo Amaldi, Paris 30.06.53

Amaldi's return to Rome in 1954 did not, of course, mean that he severed his links with CERN. On the contrary, over the next two decades Edoardo Amaldi exercised a considerable influence over the development of CERN in both the fields of science and of management. From 1957 to 1975 he was a member of the Scientific Policy Committee and was Chairman of the Committee for three years (1958–1960). He was a member of the CERN Council, the governing body of the Organization, for 13 years from 1960 to 1973. During this period he was elected Vice-President of Council in the years 1960 to 1962 and President of Council in 1970 and 1971. Starting in 1960, Amaldi played a leading role in the study, preparation and beginning of the physics programme with the new accelerators that CERN was building at the time: the Intersecting Storage Rings (ISR) and the 300 GeV Super Proton Synchrotron (SPS).

He was the founder and first Chairman of ECFA, the European Committee for Future Accelerators, and held this post from 1963 to 1969. This body was established to study and put forward proposals for subsequent generations of European accelerators and has continued to be a very important and influencial component of the European high-energy physics community. Amaldi frequently stressed the importance of having an external body to advise CERN on the needs and wishes of the university community in Europe, thus avoiding the dangerous possibility that the Laboratory's future projects would be exclusively decided internally. When ECFA held its meetings at CERN, Amaldi was always careful to emphasize that the Committee were the "guests" of the Laboratory so as to establish their independence from the Organization.

In 1968–69 he was the Chairman of the 300 GeV Project Steering Group whose task it was to nurture the plans for a new accelerator which would allow Europe's scientists to remain competitive with their counterparts in the United States at a time when many governments were extremely loath to make new and important investments in high-energy physics. In fact Edoardo Amaldi had the satisfaction of being the CERN Council President in February 1971 when, after about six years of debate and negotiation, the Member States agreed unanimously to go ahead with the 300 GeV project. With that decision the future of European high-energy physics was assured for 15 more years. Of course, with his group of researchers, he took an active part in the CERN physics programme, and ran, amongst others, an experiment at the ISR.

Among the many other duties one has to recall that Amaldi was Vice-President (1948–54), and President (1957–60) of IUPAP, the International Union of Pure and Applied Physics. It is worth noting that this institution is in charge of organizing the big international symposia and served a very important role, in sometimes difficult conditions, at the time of the cold war, in helping provide a link between physicists in the whole world. Amaldi himself went to Poland in 1947, to India in 1950 and to Japan in 1953 to review the work going on in Italy at conferences organized by IUPAP.

In 1958 and 1959 he was Chairman of the EURATOM Scientific and Technical Committee, followed by a further two years as an ordinary member. From 1968 to 1978 he was Chairman of the Scientific Committee for Physics of the Solvay Foundation (Brussels), of which he continued to be a member until 1988.

Amaldi's Contribution to Other European Scientific Organizations

Amaldi was not only a crucial figure in the foundation of CERN, but also five years after its birth invited the European governments to come together to *"make it possible for European scientists to collaborate in the study and exploration of outer space" [105].*

The Soviet Union had launched its Sputnik in 1957 and the United States had replied with the establishment of NASA (National Aeronautics and Space Administration) in 1958. It was important for Europe to take part in the scientific competition. Otherwise, he said, *"in twenty years we shall find ourselves separated by an insuperable gulf between those countries that can launch space vessels and those that cannot".*

Within a year a conference was held (at CERN, it should be added) and in 1961 a commission began working on a European space programme. In 1964 ESRO (European Space Research Organization) was born, in turn generating the great ESA initiative (European Space Agency). For two years (1980–81) he was Chairman of the Scientific Programme Committee (SPC) of ESA and also of its Space Science Advisory Committee (SSAC) during 1982 and 1983.

His commitment to CERN and ESRO was inspired by two basic considerations, in addition to genuine scientific curiosity: the independence of science from military purposes and the danger to scientific liberty when military interests intervened; and the notion that ventures in fundamental science warranted the consistent collaboration of all European nations. Amaldi was a convinced European before many others. To compete with the United States and the Soviet Union, national differences had to be set aside and forces had to be combined. With the great success of CERN and of the "Ariane" programme and Europe's current highly competitive position in space technology today, the importance of Edoardo Amaldi's determined initiatives can be fully appreciated.

Amaldi's scientific work in the period 1947–75

In the period 1947–55 Amaldi moved into a neighbouring field of science, that of cosmic rays. He thought that the interests of his Institute at Rome lay in switching attention to what we nowadays call the field of elementary particles, and that cosmic rays were the most useful source for such studies. In many ways the study of nuclei had come of age and what was needed was a finer tool for plumbing the heart of matter in research at greater energies and shorter wavelengths. Like other physicists he thought that the high-energy field would be the most direct way of moving towards a new and more advanced vision of the natural world and the Universe. He also saw that the accelerators which had been built or, which were under construction in the United States were much more powerful than those (such as the Sanitás Cockcroft-Walton) which Italy could afford. Taking this into account, he decided after the war to completely change his field of research and use cosmic rays, which are available to everybody.

The earliest of these investigations (1950–53) were in fact not concerned directly with nuclear reactions, or strong interactions. Study was made of the interactions between fast muons (the μ mesons of the period) and nuclei [73–76, 78], and in so doing the observation that muons were non-nuclear in nature was confirmed: below energies of 10 000 MeV they failed to show strong interactions, but the structure of nuclei could be investigated and, within limits, the shell model of nuclei was confirmed [75, 80, 81]. The measurements were made on iron and lead, using gas counters (Geiger-Müller counters) with C. Castagnoli, G. Fidecaro, A. Gigli Berzolari, L. Mezzetti, S. Sciuti and G. Stoppini. Parts of the group's experiments were carried out underground in a cavern constructed for a hydro-electric power plant [82–84, 86].

Edoardo Amaldi, G. Bernadini and E. Pancini at the cosmic ray laboratory in Cervinia, Testa Griga (3500m) 21 March 1948

Amaldi then took up the study of cosmic rays with the new technique of nuclear emulsions; this technique had then come into its own, for identifying all fast charged particles, even those that ionize weakly, because of their high energy. Using nuclear emulsions, the group led by Amaldi studied the decay of various new particles which were at that time open to question and contradictory, and are nowadays known essentially under the name of K mesons. Without going into detail, it should be noted that for many years Amaldi was renowned internationally in the study of what was then called the θ-τ puzzle [87–93]. He gave many review talks on this subject and his summaries of the experimental status of the θ-τ puzzle were used by everyone in the field [96, 101]. This work took place between 1953 and 1955, in collaboration with Baroni, Cortini, Franzinetti and Manfredini. During that period a cosmic-ray event was observed which could, though not absolutely certainly, be attributed to the annihilation of an antiproton [95]. Much has been written about this event which did not show the full energy release of the rest masses of the antiproton and nucleon which were supposed to annihilate. The authors themselves were very critical about the interpretation, and this example shows how careful and cautious Amaldi always was in interpreting all his experimental results.

In the period 1955–60 Amaldi once again began working, using the nuclear emulsions technique, with his old colleague and friend Emilio Segré, through a project developed between the Universities of Berkeley and Rome to investigate the annihilation of antiprotons produced in emulsions at the Berkeley Bevatron [97,98,99]. This project was also linked with the names of Ferro-Luzzi, Bellettini and Castagnoli [103, 104].

The antiproton was the long-sought-after particle and the glorious discovery of those years, theoretically anticipated and verified by new particle detectors invented in the nineteen-forties and fifties. The discovery of the antiproton and the antineutron is bound up with the names of Segré and Chamberlain — who were awarded a Nobel prize for this work — and of Amaldi and his group.

Amidst all this scientific activity Amaldi found the time to return to his old love, neutron physics, to write the 659 pages of "The production and slowing down of neutrons", in which he summarized decades of direct experience and study. This work was published as Volume XXXVIII/2 of the Handbuch der Physik [191].

In 1960 the Rome group discovered the particle $\bar{\Sigma}^+$ [106]. Between 1961 and 1968 Amaldi and his co-workers developed a series of experiments [108, 110, 111, 120, 129] for identifying the magnetic monopoles, suggested by Dirac since 1931 using the arguments of symmetry and coherence, and based on electromagnetic theory. Amaldi became, along with many others, fascinated by Dirac's elegant hypothesis which explains the quantization of electric charge and started a new series of experiments. American physicists too, such as Luis Alvarez and E.M. Purcell, were engaged in parallel studies, along with the Italian Giacomelli from Bologna. The magnetic monopole was not discovered but the results meant that its existence could be ruled out within certain, at that time interesting, limits of mass and half-lives. Amaldi also wrote a paper on this subject in collaboration with Nicola Cabibbo [129].

In 1965 and 1966, in the spirit of looking for unexpected and unpredicted phenomena, Amaldi, in collaboration with his old friend Mario Ageno, performed a series of experiments to search for effects of the centrifugal force on the weak decay of nuclei [116]. Fully understanding the slight chance that they had of finding positive evidence of such an effect, they called their search "EVP - Esperimento di Vecchietti Pazzerelloni", which loosely translated means the "Experiment of slightly crazy old dodderers".

The Frascati National Electronsynchrotron started up in 1959–60, much inspired and stoutly defended by Amaldi [148]. Starting in 1969, he and his group carried out a number of experiments on the electro-production of π-mesons. They were concerned with measurement of the cross-section of this process close to threshold, and Amaldi's group managed to deduce the axial form factor of the nucleon [122, 123–126, 128]. The subject was very rich both experimentally and theoretically, and accordingly he wrote a book on it in collaboration with Sergio Fubini and Pino Furlan [195].

After the Frascati experiments, Amaldi came back to the monopole search, but this time with a differenct approach. In the period 1973–75, using the ISR at CERN, which Amaldi had helped promote, the same group from the University of Rome (which included M. Beneventano and B. Borgia) in collaboration with a group from the Brookhaven National Laboratory (L. Yuan et al.), made an experimental study of the events in which many gamma rays are emitted in proton-proton collisions. These measurements provided an upper limit for the production cross-section of Dirac monopole-antimonopole (virtual) pairs which annihilate each other instantaneously with the emission of the order of 137 gamma rays, a process suggested by Ruderman and Zwanziger in 1969 to explain why isolated monopoles had not been observed by any group looking for them. However, as was demonstrated shortly afterwards (1974) by G. 't Hooft and A.M. Polyakov, unification theories require the existence of magnetic monopoles, but with such high masses that hitherto no experiment has succeeded in producing them. As a by-product of the ISR experiment, a first signal of single photon production in high-energy proton-proton collisions was observed [145].

The unfinished search for gravitational waves

From 1971, Amaldi, along with G. Pizzella, G.V. Pallottino and later with I. Modena, C. Cosmelli, S. Frasca, F. Ricci et al., devoted himself to the development of gravitational-wave cryogenic resonance detectors. Edoardo Amaldi's interest in this type of experiment had already been aroused in 1962, after having attended a course in Varenna where he listened to a series of lectures given by Joe Weber. During the following years, he tried several times to organize an experimental group for research in general relativity. He finally succeeded in 1970, when an experimental group was formed at the University of Rome with the aim of designing and constructing cryogenic resonant detectors for the search of gravitational waves.

The experiment started as a collaboration with Professor W. M. Fairbank from the University of Stanford and Prof.W. Hamilton from the University of Louisiana who, following the pioneer work of Weber, had proposed to make use of very low temperatures for reducing the noise of the apparatus. The design of a large cryostat for cooling a 5t aluminium bar started immediately, but the Rome group soon realized that the best approach was to go through smaller steps.

The scientific activity of Amaldi in the gravitational-wave research is documented by several papers which show the progression of the experiment that consisted in the realization of various cryogenic resonant antennas of increasing size: small antennas (20 and 30 kg), an intermediate antenna (389 kg) and a large antenna (2300 kg). This characteristic approach in stages was not followed by the other groups building antennas and it is at the origin of the relatively rapid pace of the Rome group.

In 1974 a cryostat was built at the Physics Institute of the University of Rome, capable of cooling alluminium cylinders with mass of 30 kg down to 1.1 K (-272° Celsius). The key experimental results with these antennas are documented in detail [135, 136, 138, 142] and show, for the first time, that it is indeed possible to measure the brownian noise of large bodies cooled at the liquid-helium temperature. Moreover, by measuring the behaviour of the aluminium bars at low temperatures, it was found that the "merit factor" Q increases by orders of magnitude when the bar is cooled from room temperature to 1.1 Kelvin. This feature allows experiments to reach sensitivities that are larger than were predicted when the use of low temperatures was suggested. Finally, this first step led to the development of sophisticated algorithms for data analysis, with which the authors established an upper limit for the gravitational radiation at the frequency of 8580 Hz with a noise temperature below 1 Kelvin.

Between 1974 and 1978, a cryostat for cooling a bar with a mass of 389 kg was built at the CNR Laboratory for Space Plasma in Frascati. The scientific activity undertaken with this antenna is documented mainly in papers [144] and [149]. The basic problem, which was later solved, was to find the best possible bar suspensions. These suspensions, after many trials, turned out to be the same as those used by Weber with the addition of a filtering stage. With this antenna, for the first time, a cooled amplifier based on a FET (field effect transistor) was used, enabling a noise temperature of 0.28 Kelvin to be obtained. In order to reach this low noise, for the first time an analysis based on a Wiener-Kolmogorof filter was employed, which maximizes the signal- to- noise ratio. This antenna was operated continuously for more than one month, giving valuable data which was analyzed along with data taken from an antenna installed in Maryland by searching for coincidence events.

In 1979, an agreement was signed with CERN for the installation of a large cryostat capable of keeping a large aluminium bar of 2300 kg at the temperature of liquid helium. The reason for installing the experiment at CERN was the difficulty, at that time, to have a large and efficient cryogenic facilities in Italy. According to the agreement, CERN would supply the space, the cryogenic liquids and computing facilities whilst the experiment would be run by the Rome group. The scientific work with this antenna is documented in papers [155,165,169,171] and [177]. Initially, a room-temperature antenna with a mass of 2300 kg and equipped with piezoelectric ceramics was constructed with the purpose to realize a mechanical suspension and data acquisition system (this antenna was later moved to Rome). Then the "Explorer" cryogenic antenna, built in Italy, was installed at CERN. It consisted of an aluminium cylinder with a mass of 2300 kg equipped with a resonant capacitive transducer followed by a d.c. SQUID amplifier. This antenna operated for several months in 1986. The noise was as low as 15 mKelvin, but occasionally it had large disturbances due to the instability of the system. Its performance was improved in 1989, when it was operated at 2 Kelvin (helium superfluid region) and a noise temperature of 5 milliKelvin was achieved. This noise corresponds to a sensitivity of h

$= 7x10^{-19}$, h being the perturbation of the metric tensor. For a long time this was the best sensitivity ever reached, and also one order of magnitude better than that of the non-resonant antennas. With the data recorded during 1986, a triple-coincidence experiment was performed with the antennas (of smaller sensitivity) available in Stanford and Louisiana. The results were: a) a new upper limit for gravitational radiation; b) two coincidences between the Rome and the Stanford antennas in a period of a few days with the probability of 1% to be due to chance [181].

In 1984, the room-temperature antenna originally developed at CERN was installed in the Physics Department of the University of Rome. The purpose of this antenna (called "Geograv") was to have a detector operating continuously with high reliability even if the sensitivity was relatively low, to develop a new and more efficient system of data acquisition and analysis, and to study some large signals observed in 1980 by means of the small and intermediate antennas. These signals, the study of which is described in papers [150 to 152], appeared to be correlated with the Earth's oscillations triggered by earthquakes. "Geograv" remained in operation continuously for four years and, although it did not confirm in a conclusive way the correlation with the Earth's oscillations, it was in operation on 23 February 1987 at the time of the explosion of the supernova SN1987A in the Large Magellanic Cloud.

A few days after learning about the supernova a correlation was found between the "Geograv" data and the Mont Blanc neutrino detector data, the neutrino signals being delayed by 1.4 s with respect to the "Geograv" signals [178, 184]. Since that time, because of the rarity of a supernova event, all available data has been studied, including data of another room-temperature antenna installed in Maryland and of other particle detectors installed in Kamioka (Japan), Baksan (USSR), Frejus (France) and of the experiment IMB installed in the USA. The results of this more complete analysis confirmed the previous finding, but the physical interpretation of the observations was lacking, because the sensitivity of "Geograv" was too small, according to standard evaluations, to allow the detector to observe gravitational waves emitted during the SN1987A outburst. The work done on this subject was described in two papers [188, 190].

Edoardo Amaldi was convinced that two further steps were necessary to complete 20 years of searching for gravitational waves. The first one seems trivial, but it is not: the experiment had to be run continuously over many years. The second step was to increase the sensitivity by cooling an antenna to ultra-low temperatures in the region of 50 milliKelvins. For this purpose a new large cryostat (called "Nautilus") was constructed by the Rome group and tests started at CERN a few months after Amaldi's death. The final goal of this detector was the observation of gravitational collapses occurring in the Virgo cluster.

The contribution of Edoardo Amaldi to the gravitational-wave experiments had many facets. In Rome, he started this activity with great determination, abandoning the fields in which, up to that moment, he had been working. He brought with him the weight of his experience and of his deep physical insight, in particular in the interpretation of the experimental data. He played a major role in the installation of the large cryogenic antennas at CERN. His contagious enthusiasm was essential for keeping the research group united for so many years. He taught his co-workers how to tackle difficult problems, to find out the most important point and pursue it with strong determination to the very end, in a simple and pragmatic way, and to never be discouraged. Certainly, when gravitational waves are discovered, Amaldi's contribution will not be forgotten either by his colleagues or the whole physics community.

A man of ideals

There is a perfect coherence between Edoardo Amaldi's primary interest for scientific activities and his human and civil engagement. He derived the sense of responsibility concerning the very great risks to mankind, implicit in any prospective use of nuclear armament, from the knowledge of the crucial part that physicists, and himself in particular, had played in making possible the release of energy from atomic nuclei. Because of his character, when faced with this problem, he would not let himself be drawn into considerations and commiserations, but plunged directly into action. He was fully conscious of the limits imposed on any initiative created by groups or individuals with matters involving the vital interests of the major countries and the whole of humanity; but equally fully convinced that the international initiatives of men of goodwill could always influence decisions and events and furthermore, that one should never give up playing one's part.

Although he consistently rejected the military application of nuclear energy, he was a firm believer, despite the recent trends of opinion, that the peaceful utilization of nuclear energy was good, provided that it was properly implemented, in particular in Italy which has no national energy resources. Since he had a natural tendency to speak out, his clashes with environmentalists and other opponents of nuclear energy became memorable. His position on energy can be summarized as follows:

It is no new idea to close down nuclear power stations and replace them with solar power and the energy which can be derived from the winds and seas. These sources, however, can provide only a small fraction of the energy needed for the next decade and France had tried to use these techniques only to discover the results were disappointing and thereupon, the country embarked on a massive programme of nuclear power stations. To close down the plants would mean transforming society and our lifestyles. It would mean having to convince people to live in greater discomfort, which would be hard to do, and would inevitably lead to unemployment. Abandoning nuclear power would mean increasing dependence on nations that have set their sights on this form of energy. The same dependence that today binds us to the oil producers. Amaldi looked at nuclear energy produced with fusion processes as a stopgap solution waiting for the industrial development of nuclear fusion. This philosophy, which stemmed from his training and research work, brought him into open conflicts with environmentalists. There was a memorable outburst, during a television debate on the Chernobyl event, at Gianni Mattioli, who was proposing to generate the power needed by Italy with windmills and solar energy conversion. Mattioli later became a 'Green' member of the Italian Parliament partly because of the notoriety that followed this incident. He himself was a physicist and had once been Amaldi's student. Mattioli commented after Amaldi's death

> *"The day after the incident, during which he called me an imbecile on the television, our relations resumed on the most friendly footing. For my part, I always had a great admiration for Amaldi's work, who after the war continued the search for a new identity for physicists in the peaceful use of nuclear energy".*

Edoardo Amaldi has never collaborated in programmes directly connected with the manufacture of nuclear weapons, but the possibilities of being involved in such activities were certainly understood by him. He had deeply reflected on the implicit responsibility of decisions of this type. As has already been mentioned, he had quite deliberately decided at the end of the thirties to abandon all research in Italy in those fields of physics which could have led to the possible military use of nuclear energy; preoccupied as he was that the governing authorities of the Fascist regime could have taken a particular interest in this field. Moreover, before the war, Edoardo Amaldi had considered the possibility of moving to the United States and he knew very well that, had he done so, he would probably have chosen to collaborate in the American project to construct the atomic bomb, in the same way as many of his friends, notably Fermi, Segré and Pontecorvo, had done. Amaldi had this to say on the subject (J. Phys. France, Colloque C8, supplément au No. 12, Tome 43, décembre 1982);

> *"During the years after the end of World War Two I have often asked myself what would have been my attitude in front of these problems "if", in 1939 I had found a job in a University in USA, and "if" some time later, somebody would have asked me to enter the Manhattan Project.*
>
> *After long and repeated consideration of this purely hypothetical case, I arrived to the conclusion, that after a few changes of mind and a lot of suffering, I would have accepted, as a duty, an extremely unpleasant duty, not towards my country of origin or this or that group of people, but towards the part of Humanity that in spite of all its unpleasant qualities, still represents the best in real existence.*
>
> *This thought brings me to my final remark. Public declarations against nuclear weapons or other mass-destruction systems should be done whenever possible and should be signed by as many scientists as possible. We should, however, be prepared to the idea that if in the future these same people find themselves in a climate of continuously and rapidly increasing terror, earlier or later, some of them, or perhaps many of them, will feel justified or even morally obliged to drastically change their mind. Let us hope that situations similar to that met by mankind during the early 40's will not be faced again."*

In July 1955 the "Russell-Einstein Appeal" was made public (from the names of the main writer and of its most illustrious signatory), in which the international scientific community was invited to do its utmost, overcoming the characteristic divisions of those years of the cold war, to ward off the very serious danger implicit in the use of nuclear and thermonuclear weapons. Following this appeal, a first meeting of scientists took place in July 1957, in the Canadian village called Pugwash; from that first meeting the famous "Pugwash Movement" was born. Edoardo Amaldi — who was by this time an illustrious scientific personality, not only in Italy, but in the whole of Europe — was involved in this initiative from its very beginning and never hesitated to engage himself throughout his life. For contingency reasons he could not attend the very first meeting in Pugwash, but took part in the following meeting in Europe (in 1958) and was invited to become member of the Managing Committee of the Pugwash Movement as soon as the appropriate structure was created (1962).

Edoardo Amaldi was an active member of this Committee up to 1973, when he chose to retire, as he wanted to reduce, in so far as was possible, his engagements abroad, so as to dedicate more of his time to his wife Ginestra, who, since 1971, was tragically confined to a wheel-chair. From this date until his death, a period of eighteen years, Edoardo Amaldi, in taking care of his wife, showed the characteristics of involvement, constancy, the refusal to be discouraged and also good humour that he displayed in all his activities. He nonetheless continued to work in physics, cope with all his responsibilities as well as participate in disarmament activities.

On 27 November 1982, a delegation of Italian physicists, led by Amaldi, presented a document to the President of the Italian Republic Sandro Pertini, expressing their concern over the spiralling arms race and, more particularly, over the possibility of the installation of 'cruise missiles' in Italy and throughout Europe (during the audience, the President highly commended and praised Edoardo Amaldi). The conclusion of the document states:

> *".... we unanimously hope that ... talks .... will lead, in the shortest possible time, to an agreement not simply to stop this spiralling nuclear arms race in Europe but will start a process of nuclear arms reduction; above all it is our hope that the European Nations, and Italy in particular, will play an active and autonomous part in this sense in every international organization and more so in NATO."*

The document in question is important as it contains a calm analysis of a problem offering elements of information and reflection, with, at the same time, a wide consensus on the subject under discussion, from people with quite different ideological backgrounds and differing political opinions. The essence of Edoardo Amaldi's moral position was always a deep faith in human reason and a corresponding dislike for the evil of irrationality.

The success of this document gave birth to the Constitution of the Union of Scientists for Disarmament (Unione degli Scienziati Per Il Disarmo, USPID). Subsequently this has actively operated to keep alive the debate on such themes in Italy and to spread factual information. It has organized, among other things, various international meetings in Italy, with the participation of eminent international experts in the field; these have met with great success thanks to the support and the participation of Edoardo Amaldi. In the same light the creation, with Carlo Schaerf, of the initiative which now bears the name of ISODARCO (International School On Disarmament And Research on Conflicts) must be mentioned; Edoardo Amaldi was its President from the very beginning (1966) right up to his death.

As previously mentioned, Amaldi led a delegation of Italian scientists to the International Forum organized by Secretary-General Gorbachev in Moscow in 1987. He gave a speech on "International collaboration in Science" at the end of which he presented to Academician Velikhov, who was chairing the meeting, a list of names of Soviet refusniks prepared by the International Federation of Scientists for Soviet Refusniks and a list of names of Prisoners of Zion saying that he hoped,

> *"A rapid solution of these human problems will be received with a wide consensus and admiration for the present Soviet leadership by many scientists and scolars of the Western countries and will facilitate and shorten the road towards a closer co-operation in many old and new cultural, scientific, technological, industrial and economic domains".*

E. Amaldi at his 70th birthday celebration at the Botanical Gardens, Rome

It is also to Edoardo Amaldi that we owe the creation, in the framework of the Accademia dei Lincei in Rome, of a working group on International Safety and Arms Control (SICA).

As part of the SICA initiative, Edoardo Amaldi (together with Ugo Farinelli and Cesare Silvi) promoted specific research on the concrete possibilities of re-using, for peaceful purposes, fissile material contained in nuclear warheads once they had been dismantled in the process of nuclear arsenal reduction. One week before his death, Edoardo Amaldi's last public speech was a detailed quantitative analysis of this proposal [191].

The activity of the SICA group was stimulated by an intense exchange of opinions and discussions with the corresponding groups of the United States National Academy of Sciences (CISAC) and the U.S.S.R. Academy.

The first meeting, held in Rome from 23-25 June 1988, between Italy and the U.S.A was followed by a second meeting from 6-9 June 1989, enlarged to include European, American and Russian Academies, and dedicated to Security and Arms Control, and related problems.

The programme of the 1990 edition of this Conference had already been fixed when Edoardo Amaldi passed away in December 1989. The Conference, which took place from 4-7 June, was the first to bring together the Western Academies and a number of the newly free Academies of the Eastern European countries, Yugoslavia, Romania and Poland. The interest in the problems debated was such that it was decided to export this kind of Conference, with the name of "Amaldi Conference" outside Rome. The next Amaldi Conference was held in Cambridge (U.K.) from 8-10 July 1991 under the auspices of the Royal Society. It was devoted primarily to disarmament and arms security; nuclear, chemical and biological weapons; arms trade and conversion. Again there was wide acceptance of the view, clearly presented by W.K.H. Panofsky, that Academies have a fundamental role in the study of security and in working for disarmament and peace.

Amaldi the historian

Amaldi's contribution as a writer of history started relatively late in his career. He was a historian of his times. His studies of history began after the war, under the spur of the events he had witnessed and of the reconstruction which he had guided, and then went on to cover events which and scientists who, in his opinion, should not be forgotten.

In 1966 he published the first of two biographies [117, 183], of the physicist Ettore Majorana, who died at the age of 32 in 1938. Amaldi wrote several memoirs of scientists with whom he had worked, including Enrico Persico, Ettore Pancini and Gian Carlo Wick [166]. A special mention must be reserved for Amaldi's work on the life of Bruno Touschek, "The Bruno Touschek Legacy (Vienna, 1921 – Innsbruck, 1978)" [156]. A physicist of great talent, Touschek was responsible for the initial project for the first electron-positron storage ring in the world, the famous ADA (Anello Di Accumulazione), and brought the project to completion together with the physicists of Frascati. At the time of his death, Amaldi left a finished but unpublished book: "The adventurous life of Friedrich Georg Houtermans, physicist", who was imprisoned both in the Soviet Union and, after the Ribbentrop–Molotov agreement, in Nazi Germany [199].

An entire article could be written on Amaldi's historical works. One can only marvel at his ability to find the time, in a life already so full of activity, to write works of great detail and commitment. In 1968 he wrote the history of CERN [121] and later he published "From the discovery of the neutron to the discovery of nuclear fission", with its 1000 references [162]. However some of his major works must be mentioned. A work which all those interested in the history of science should read is "The years of reconstruction", printed in Italian and English in 1979 [147]. At the beginning of this short work we are faced with the collapse of the "Group of Rome" with the departure of Fermi and the rapid descent into the moral confusion and practical difficulties which faced those scientists who stayed in Italy during the war years. Amaldi tells how important research was maintained in the most difficult conditions and how, little by little, Italian institutions were reanimated after the war. The style is simple and not unnecessarily erudite yet one feels it has the rigour of a historian who bases his text strictly on his sources and who has no interest in sensationalism. Throughout "The years of reconstruction" Amaldi is typically modest as to his own contribution during this period.

Amaldi the teacher

Edoardo Amaldi took very seriously his responsibility to pass on to others the benefits of his experience and research. His courses on physics instilled an enthusiasm and devotion to the subject in many of Europe's current senior physicists. As Francesco Calogero says, *"Edoardo Amaldi was a teacher of legendary clarity. I can personally testify, having followed as a student his Course on General Physics or, as it was called by the students then and still these days, FISICONA (the Grand Physics). He always showed great interest for the didactic and vulgarization activities..."*. He had a clear delivery as a lecturer, speaking with simplicity and conciseness. His books on electricity, magnetism and optics [193, 199] was a guidebook for many years, for both students and teachers. Another major contribution by Amaldi to education in Italy, or rather by Edoardo, his wife Ginestra and, later, his son Ugo, was their physics text-books for secondary schools which have by now sold more than a million copies.

Conclusion

Edoardo Amaldi was present at and active in some of the great turning points of European science from the 1930s onward.

It could be argued that no scientific research in the 20th century has generated such political, moral and social reverberations as the work on slow neutrons of Fermi's "Group of Rome". However, to stress the importance of this period when Amaldi was still a young man does not of course belittle his later achievements in the study of cosmic rays, particle physics and gravitational waves. Although Edoardo Amaldi did not like to be congratulated by colleagues on his appointments to important functions because he considered himself above all as a man of science, there can be no doubt that he was one of Europe's great post-war scientific statesmen. It is above all as a man of vision, as a man guided by powerful and timely ideals, as a man determined to build new scientific institutions, that Edoardo Amaldi has left an indelible trace on history.

Amaldi was inspired by two clear principles. First he was convinced that science should not be pursued for military purposes. Amaldi spent much of his life ensuring that basic research in his field received the funds and the facilities which it needed in order to prosper, yet he was emphatic that it should not become militarized. This does not mean that he thought that science had no social significance. On the contrary he was well aware that "big science" in particular stimulated industry, and trained highly qualified specialists who could be useful in many sectors of the economy. Secondly, Edoardo Amaldi was a dedicated European. He realized very early that no single European nation could hope to hold its own scientifically and technologically. To compete they had to collaborate. Only by pooling their resources could they restore the old continent, the cradle of modern science, to its former role, on a par with the United States and the Soviet Union. As we have seen, these were not simply pious hopes or abstract ideals. Amaldi was determined to see them put into practice. This is clearly demonstrated by the key role he played in the launching of CERN and the European Space Research Organization (ESRO).

It is not only Europe as a whole that should be grateful to Amaldi for the current strength of its scientific institutions but also his native Italy. His role in the post-war rehabilitation of physics in Italy was enormous. For Edoardo Amaldi there was never any conflict between being a fervent European and protecting the interests of his national scientific community.

Historian, teacher, man of ideals, all these facets of Edoardo Amaldi's life have been referred to but it is also because of his human qualities that he will be remembered. His exemplary coolness of mind, his total sincerity, his respect for the deserving, his unwavering intellectual and moral honesty, and his constant affection and commitment to his family were the hallmarks of this remarkable man.

The lessons of his life will remain as a source of inspiration for the future of a successful and peaceful scientific Europe.

I should like to thank John Krige and Giorgio Salvini along with Mario Ageno, Ugo Amaldi, Francesco Calogero, Guido Pizzella and Bruno Pellizzoni for their invaluable contributions to this memoir.

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Academic Honours of Edoardo Amaldi

He was a member of the Accademia Nazionale dei Lincei (1948), and its President in 1988 and 1989, of the Accademia Nazionale dei XL (1957) and of many other Italian and foreign academic societies, including the Uppsala Academy of Sciences (1957), the Soviet Academy of Sciences (1958), the American Philosophical Society of Philadelphia (1961), the National Academy of Sciences (USA) (1962), the American Academy of Arts and Sciences of Boston (1962), the Royal Dutch Academy (1963), the Accademia Leopoldina (Deutsche Akademie der Naturforschung) of Halle, GDR, (1964), the Spanish Academy of Sciences (1966), the Royal Society (1968), and the Royal Swedish Academy (1968).

He held honorary doctorates from the Universities of Algiers (1959), Glasgow (1972), Oxford (1974), and Cagliari (1989), and was awarded the Seal of the Sorbonne (1964).

LIST OF PUBLICATIONS OF PROFESSOR EDOARDO AMALDI

1 - "Sulla dispersione anomala del mercurio e del litio"
(In collaboration with E. Segré)
Rend. Acc. Lincei 7, 919–921 (1928).

2 - "Sulla teoria dell'effetto Raman"
(In collaboration with E. Segré)
Rend. Acc. Lincei 9, 407–409.

3 - "Sulla teoria quantistica dell'effetto Raman"
Rend. Acc. Lincei 9, 876–881 (1929).

4 - "Über die Streuung von Röntgenstrahlen an Wasser"
Z. Phys. 32, 914–919 (1931).

5 - "Sulla distribuzione delle molecole in un liquido"
Riv. Nuovo Cimento 9, CXLI (1932).

6 - "Über den Ramaneffekt des CO"
Z. Phys. 79, 492–494 (1932).

7 - "Ramaneffekt des gasförmigen Ammoniaks"
(In collaboration with G. Placzek)
Naturwiss. 20, 521 (1932).

8 - "Spettri di assorbimento degli alcalini nel campo elettrico"
(In collaboration with E. Segré)
Ric. Scient. 42, 41–43 (1933).

9 - "Über das Ramanspektrum des gasförmigen Ammoniaks"
(In collaboration with G. Placzek)
Z. Phys. 81, 259–269 (1933).

10 - "Series of alkaline atoms in an electric field"
(In collaboration with E. Segré)
Nature 132, 444 (1933).

11 - "Effetto del campo elettrico sul limite della serie del potassio"
Rend. Acc. Lincei 19, 588–594 (1934).

12 - "Effetto della pressione sui termini elevati degli alcalini"
(In collaboration with E. Segré)
Nuovo Cimento 11, 145–156 (1934).

13 - "Nuovi radioelementi prodotti con bombardamento di neutroni"
(In collaboration with E. Fermi, F. Rasetti, E. Segré)
Nuovo Cimento 11, 442–451 (1934).

14 - "Segno ed energia degli elettroni emessi da elementi attivati con neutroni"
(In collaboration with E. Segré)
Nuovo Cimento 11, 452–460 (1934).

15 - a) "Effetto della pressione sui termini alti della serie degli alcalini"
(In collaboration with E. Segré)
Ric. Scient. 5, 53 (1934).
b) "Effect of pressure on high terms of alkaline spectra"
Nature 133, 141 (1934).

16 - "Radioattività provocata da bombardamento di neutroni"
(In collaboration with O. D'Agostino, E. Fermi, F. Rasetti, E. Segré)
Ric. Scient. 5, 452–453 (1934).

17 - "Radioattività provocata da bombardamento di neutroni. IV"
(In collaboration with O. D'Agostino, E. Fermi, F. Rasetti, E. Segré)
Ric. Scient. 5(1), 652–653 (1934).

18 - "Radioattività provocata da bombardamento di neutroni. V"
(In collaboration with O. D'Agostino, E. Fermi, F. Rasetti, E. Segré)
Ric. Scient. 5(2), 21–22 (1934).

19 - "Azione di sostanze idrogenate sulla radioattività provocata da neutroni"
(In collaboration with E. Fermi, B. Pontecorvo, F. Rasetti, E. Segré)
Ric. Scient. 5(2), 281–282 (1934).

20 - "Radioattività provocata da bombardamento di neutroni. IV"
(In collaboration with D'Agostino, E. Segré)
Ric. Scient. 5(2), 381–382 (1934).

21 - "Radioattività provocata da bombardamento di neutroni. VII"
(In collaboration with O. D'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, E. Segré)
Ric. Scient. 5(2), 467–470 (1934).

22 - "Artificial radioactivity produced by neutron bombardment"
(In collaboration with E. Fermi, O. D'Agostino, F. Rasetti, E. Segré)
Proc. Roy. Soc. London A146, 483–500 (1934).

23 - "Le orbite s degli elementi"
(In collaboration with E. Fermi)
Mem. Acc. d'Italia 6, 119–149 (1935).

24 - "Nuove radioattività provocate da neutroni. La disintegrazione del boro"
Nuovo Cimento 12, 223–231 (1935).

25 - "Radioattività provocata da bombardamento di neutroni.VII"
(In collaboration with O. D'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, E. Segré)
Ric. Scient. 6(1), 123–125 (1935).

26 - "Radioattività indotta da bombardamento di neutroni. IX"
(In collaboration with O. D'Agostino, E. Fermi, B. Pontecorvo, E. Segré)
Ric. Scient. 6(1), 435–437 (1935).

27 - "Radioattività provocata da bombardamento di neutroni. X"
Ric. Scient. 6, 581–584 (1935).

28 - "Sull'assorbimento dei neutroni lenti"
(In collaboration with E. Fermi)
Ric. Scient. 6(2), 334–347 (1935).

29 - "Sull'assorbimento dei neutroni lenti. II"
(In collaboration with E. Fermi)
Ric. Scient. 6(2), 443–447 (1935).

30 - "Artificial radioactivity produced by neutron bombardment. II"
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Proc. Roy. Soc. London 149A, 522–558 (1935).

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(In collaboration with E. Segré)
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(In collaboration with E. Fermi)
Ric. Scient. 7(1), 56–59 (1936).

33 - "Sul cammino libero medio dei neutroni lenti nella paraffina"
(In collaboration with E. Fermi)
Ric. Scient. 7(1), 223–225 (1936).

34 - "Sui gruppi di neutroni lenti"
(In collaboration with E.Fermi)
Ric. Scient. 7(1), 310–313 (1936).

35 - "Sulle proprietà di diffusione dei neutroni lenti"
(In collaboration with E. Fermi)
Ric. Scient. 7(1), 393–395 (1936).

36 - a) "Sopra l'assorbimento e la diffusione dei neutroni lenti"
(In collaboration with E. Fermi)
Ric. Scient. 7(1), 454–503 (1936).
b) "On the absorption and diffusion of slow neutrons"
Phys. Rev. 50, 899–926 (1936).

37 - "Behaviour of slow neutrons at different temperatures"
(In collaboration with E. Segré)
Phys. Rev. 50, 571 (1936).

38 - "Un generatore artificiale di neutroni"
(In collaboration with E. Fermi e F. Rasetti)
Ric. Scient. 8(2), 40–43 (1937).

39 - "Künstliche Radioaktivität durch Neutronen"
Z. Phys. 38, 692–734 (1937).

40 - "Neutron yields from artificial sources"
(In collaboration with L.R. Hafstad and M.A. Tuve)
Phys. Rev. 51, 896–912 (1937).

41 - "Metodo fotografico per il rilievo della fluttuazione dei raggi X emessi da un'ampolla"
(In collaboration with G.C. Trabacchi)
Rend. Ist. Sanità 1, 317–320 (1937).

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Atto STPS (1938).

43 - "On the albedo of slow neutrons"
(In collaboration with E. Fermi, G.C. Wick)
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Phys. Rev. 56, 881–884 (1939).

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(In collaboration with D. Bocciarelli and G.C. Trabacchi)
a) Rend. Acc. d'Italia 10, 350–358 (1940).
b) Ric. Scient. 11, 121–127 (1940).

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(In collaboration with M. Ageno, D. Bocciarelli, B.N. Cacciapuoti, G.C. Trabacchi)
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(In collaboration with M. Ageno, D. Bocciarelli, G.C. Trabacchi)
Rend. Ist. Sanità 3, 201–216 (1940).

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Mem. Acc. d'Italia 13, 555–615 (1941).

55 - "Sulla scissione del torio e del protoattinio"
(In collaboration with D. Bocciarelli, G.C. Trabacchi)
a) Ric. Scient. 12, 134–138 (1941);
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(In collaboration with M. Ageno, D. Bocciarelli, G.C. Trabacchi)
a) Ric. Scient. 12, 139–143 (1941);
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57 - "Sull'urto fra protoni e neutroni. I"
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Ric. Scient. 12, 830–842 (1941).

58 - "Fission yield by fast neutrons"
(In collaboration with M. Ageno, D. Bocciarelli, B.N. Cacciapuoti, G.C. Trabacchi)
Phys. Rev. 60, 67–75 (1941).

59 - "Sull'urto fra protoni e neutroni. II"
(In collaboration with D. Bocciarelli, B. Ferretti, G.C. Trabacchi)
Ric. Scient. 13, 502–531 (1942).

60 - "Tubo a raggi X con catodo sostituibile"
(In collaboration with D. Bocciarelli, G.C. Trabacchi)
Rend. Ist. Sanità 5, 694–698 (1942).

61 - "Streuung von 14-MV-Neutronen an Protonen"
(In collaboration with D. Bocciarelli, B. Ferretti, G.C. Trabacchi)
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62 - "Sull'urto di neutroni contro protoni e deutoni"
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63 - "Apparecchio per la purificazione e la conservazione di idrogeno destinato a produzione di ioni"
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a) Rend. Ist. Sanità 6, 416–419 (1943);
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Naturwiss. 31, 231–232 (1943).

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