CURRICULUM VITAE

for

Rolf Kristian Eckhoff

up to 1994

1. PERSONAL DATA

I was born on the 24th November 1937 in Stavanger, Norway, as son of Dipl.-Ing. Kristian W. Eckhoff and his wife Hilde. In 1963 I married Astrid M. Endresen. We have 4 children.

2. EDUCATION AND ACADEMIC DEGREES/DISTINCTIONS UP TO 1993

Examen Artium (high school), science branch, St. Svithun's School, Stavanger, 1956.

Sivilingenior (Master of Science), Technical University of Norway, Trondheim, Dept. of Chemical Engineering, 1961.
Thesis: "Investigations of Mixing of Liquids by Turbulent Flow in Pipes".

M. Phil. (Master of Philosophy), University of London, Kings College, Faculty of Engineering, 1971.
Thesis: "The Energy Required for the Initiation of Explosions in Dust Clouds by Electric Sparks".

Dr. techn. (Doctor Technicae), Technical University of Norway, Trondheim, 1976.
Thesis: "A Study of Selected Problems Related to the Assessment of Ignitability and Explosibility of Dust Clouds".

DSc(Eng.) (Doctor of Science, Engineering, "Higher doctorate" of University of London), 1992, based on approximately 25 papers on dust explosions, gas explosions and powder technology, and a 600-page book on dust explosions in the process industries.

"Permanently Invited Guest" of the Working Party on the Mechanics of Particulate Solids, European Federation of Chemical Engineering, from 1985.

Visiting professor of Northeastern University, Shenyang, P.R. China, from 1990.

Member of "Committee of Honour" of Europex, Belgium, from 1991.

Recipient of the W. Cybulski medal for 1992, from the Polish Academy of Science. (International distinction for research on prevention of dust explosion accidents in industry and mining. Awarded only once before, to Dr. W. Bartknecht of Germany, in 1990.).

3. APPOINTMENTS

I was an employee of Chr. Michelsen Institute (CMI), Dept. of Science and Technology for more than 30 years, from January 1, 1962 to July 1, 1992, with the exception of two periods, viz. 1 $^{1}/2$ years of compulsory military service from medio 1962 to ultimo 1963, and two years of study at University of London, England, from 1966 to 1968. In September 1973 I was appointed chief scientist at CMI, with powder technology and dust explosions as my field of responsibility. In 1976 I also initiated and obtained the responsibility for CMI's research activities on gas explosions. However, from 1987 the part of the gas explosion research dealing with flow dynamics (explosion development) was, according to my own wish, handed over to others, also formally. From September 1, 1988, my official title was changed from chief scientist to senior scientific advisor, a position that I still hold after the transformation of the Science and Technology department of CMI into an independent research company, Christian Michelsen Research (CMR), in 1992. I report directly to the managing director of CMR.

In March 1992 I was appointed part time professor (Professor II) of the University of Bergen (Institute of Physics, Section of Applied Physics and Technology). This position is closely associated with professor E. Hammer's activity on "Industrial Instrumentation and Measurement Technology" (see 6.1).

4. RESEARCH WORK

The scientific research which I have conducted during my more than 30 years at CMI/CMR, has mainly been externally financed contract research for industry, research councils etc. This activity has resulted in more than two hundred CMI/CMR-reports. Quite a few of these are short test reports, whereas others are comprehensive reports on major projects. Some of the reports are M. Sc. theses produced during many years of cooperation with the Technical University of Norway in Trondheim. In section 9 some reports of works of special significance, which were not published in journals, are listed. In the following I shall mainly mention the research and development work that resulted in publications in technical/scientific journals.

4.1 Studies on an Optical Technique for Measurement of Degree of Mixing in Turbulent Liquids

This work was started in 1961 as the subject of my M.Sc. thesis. From January 1, 1962 I was employed temporarily at CMI for 6 months to carry this work to a conclusion. The results were published in an internationally recognized journal (Ref. 1).

4.2 Studies on Metallic Corrosion

During my compulsory military service I worked at the Norwegian Defence Research Establishment in 1963, studying theoretical and practical aspects of methods for preventing metallic corrosion. The results of the work were presented in a NDRE note. (Report 1).

4.3 Measurement of Particle Size in Powders

In the late autumn of 1963 I was called back to CMI to start research on the measurement of particle size distributions by means of the Coulter counter. Originally this was part of a larger research programme concerned with the production of emulsion-PVC. It was of interest to study the formation and growth of the small primary particles of sizes from 1 µm and downwards, during the polymerization process. As I worked with these problems, I realized that measurement of particle size was not only related to PVC, but to powders in general. During this period I published two papers in Norwegian journals on measurement of particle size in general (Ref. 2) and the use of the Coulter counter in particular (Ref. 3). We conducted a quite comprehensive investigation on the use of the Coulter counter for determining size distributions in Portland cement and raw mix. The results were published in full in English in a Norwegian journal (Ref. 4), whereas some general aspects were extracted and published in an international journal (Ref. 5).

However, by relying on "indirect" methods of analysis, such as the Coulter counter, one can never be sure that the particle size distribution obtained is that of the primary particles. An agglomerate of small primary particles will be counted one big particle, and the measured particle size distribution becomes coarser than the distribution of the primary particles. This problem led to the incorporation of electron microscopy in my research programme, and this presented the opportunity to publish two papers on methods of preparing particles for size analysis by transmission electron microscopy (Ref. 6 and 7). This was before the scanning electron microscope (SEM) had become common, and it was still necessary to rely on transmission electron microscopy (TEM) and replica techniques. A comparative investigation of TEM, Coulter counter analysis and analysis by means of a sedimentation centrifuge was also conducted during this period (Ref. 8). I also published a contribution to the international discussion concerning the general problem of extrapolating particle size distributions into the size range below the lower particle size limit of the experimental technique used (Ref. 9).

From 1966 the main emphasis of my scientific work was shifted from particle characterization to other parts of powder and dust technology (dust explosions). Knowledge of techniques for characterizing particles is, however, central in all types of research concerned with powders and dusts, and I attempted to maintain a certain activity in the field for some time still. In 1969 I did some special studies on the Coulter principle of particle sizing, resulting in a further paper (Ref 10). In 1970 I conducted some investigations concerning the determination of size distributions of particles in high-density powders

(tungsten and tungsten carbide), using the sedimentation balance (Report 2). I also presented a paper on the use of TEM for characterizing particles, at a national scientific symposium on powder technology in 1969 which I initiated (Ref. 11). This symposium for the first time introduced the subject of **powder technology** as a coherent field of research and development, to the scientific and industrial community in Norway. In that context I produced a paper for our main national engineering journal, introducing the field of powder technology (Ref. 12). From 1969 our National Scientific Research Council (NTNF) started to support our research financially through its various committees, and powder technological research and development in Norway has enjoyed a continued support from NTNF/NFR right up to the present (see 5.).

4.4 Particulate Air Pollutants

In the beginning of 1966 I was engaged by the Norwegian Association of Engineers to carry out a broad literature study on the air pollution problem at large. I did this in cooperation with assoc. professor O. Erga, Technical University if Norway, Trondheim, and we produced a joint survey paper on the subject in one of our national journals (Ref. 13). In 1969-70 CMI's powder research laboratory was engaged more directly in this problem area, and we conducted a series of measurements of particle size distributions and particle morphology on filter samples from the effluent gases from Norwegian aluminium production plants. We also conducted a similar investigation on particles in the effluent gases from FeSi-furnaces. My interest in this field gave rise to a presentation of a paper on characterizing fine aerosols by means of TEM (Ref. 14). In later years I have personally not been active in this field, but my close colleague and co-worker at the CMI through a number of years, Mr. W.C. Wedberg, developed an interesting and important activity in closely related areas.

4.5 Studies at University of London, UK, concerning Mechanisms for Initiation of Dust Explosions by Electric Sparks and Hot Surfaces

From the autumn of 1966 till the autumn of 1968 I had the opportunity, via a grant from NTNF, to stay at University of London, King's College, for post-graduate studies. Originally the intention was to pursue some specific investigations within the area of particle size analysis. However, professor H.E. Rose, my supervisor at King's College and Europe's first full professor of powder technology, wanted me to direct my studies with him towards mechanisms for initiation of dust explosions, primarily by electric sparks. This field was entirely new to me, and also largely new to professor Rose. I therefore had two very demanding, but also very rewarding years in London. The results obtained were brought to Norway, and a thesis was submitted to University of London in 1970. In 1971 I was awarded the degree of M.Phil. (Master of Philosophy) by this University.

4.6 Methods for Characterizing Dust Explosibility - Official Norwegian Regulations for Preventing Industrial Dust Explosions

My work with industrial dust explosions in England soon proved to be useful also to Norway. In 1970 the new import grain silo plant in Stavanger suffered a severe dust explosion, and I was called upon to assist in the subsequent investigation. Shortly after I wrote two papers in two of our national journals concerning the dust explosion problem (Ref. 15 and 16). My first research task on dust explosions in Norway was to study the initiation of explosions in clouds of silicon dust by electric sparks, on behalf of a Norwegain manufacturer of fine silicon powder (Bremanger Smelteverk). An open Hartmann tube apparatus and an electric spark generator, producing sparks of known energies, were built at CMI in 1970. Later the results of these investigations turned out to present important evidence, in the investigation of the disastrous silicon dust explosion at the Bremanger silicon powder production plant in 1972. In the following years we conducted further experimental work on electric spark ignition of dust clouds, which constituted the basis of the first part of my first doctorate thesis, and resulted in several publications (Ref. 17, 18 and 19).

In 1971, in parallel with the ongoing work on electric spark ignition, we also started the investigations on characterizing the pressure development during dust explosions in closed vessels. The emphasis was put on dusts from the grain, feed and food industries. These investigations also turned out to be long-lasting and demanding, and provided the basis for the remaining part of my doctorate thesis, and also resulted in two publications (Ref. 20 and 21).

In view of several severe dust explosion accidents that had occurred in Norwegian industry in the beginning of the 1970'ies, I approached our Ministry of Employment in 1972 and recommended that work towards producing a set of Norwegian regulations for preventing dust explosions in industry, be initiated. The Ministry decided immediately, through its Factory Inspectorate, to establish an ad hoc committee that was given the task to produce a draft for such regulations. I was acting as the secretary of the group. The regulations came into force in 1975, and after being reprinted in 1990, they are still in use, although revision of some parts is overdue.

As a natural consequence of having introduced the new regulations, a need emerged for a laboratory for characterizing ignitability and explosibility of powders and dusts in Norwegian industry. CMI's offer to establish such a laboratory was appreciated by the official authorities, and we initiated a long-term systematic programme to accomplish this task. The perfection of the laboratory has in fact been going on continuously since the start in 1970, in close contact with similar laboratories in a number of countries. Since 1974 I have been a member, the only one from Scandinavia, in Working Group SC31H-WG2 of the International Electrotechnical Commission, which is given the task to develop international standard methods for characterizing the ignitability and explosibility of dusts. Recently the European Union has initiated similar work, in which I am, on behalf of CMR, also directly involved (CEN, TC305,WG1, SG1&2).

CMI's (after 1.7.92 CMR's) test laboratory has for a long time been the central laboratory for Scandinavia. A test laboratory of this kind must never become static. It is essential that it is continuously updated both concerning equipment and knowledge, and this has to be accomplished in close contact with the international research front. Our own contributions to this process have been, in addition to the publications already mentioned, (Ref. 17-21), two Nordtest-standards (Ref. 22 and 23), and several other publications on various problems related to test methods and interpretation of test results (Ref. 24-33a). For example, I gave a paper in 1986 in the National Academy of Sciences in Washington DC, concerning the problem of predicting by laboratory tests how violent dust explosions will be in industry (Ref. 28). In September 1987 I gave a survey paper on the characterization of ignitability and explosibility of dusts at the first international conference on dust explosion in industry, in Shenyang, P.R. China (Ref. 33a). I had the pleasure to chair this symposium together with professor Deng Xufan. (7 years after, in August/September 1994, an international conference on dust explosions was arranged for the second time in Shenyang, and again I had the pleasure of being a member of the organizing committee, see 6.1 and 7).

Test methods are discussed extensively in my book on dust explosions in the process industries (see 6.2).

4.7 Powder Mechanics

The concept of Powder Mechanics was introduced internationally in the early 1970'ies by the establishment of the "Working Party on Mechanics of Particulate Solids" under the European Federation of Chemical Engineering. I had the pleasure of being one of the two Norwegian representatives to this working party for many years, from 1971/72. In 1985, however, I found it appropriate to offer my membership to my very close colleague at the CMI, Dr.techn. Gisle G. Enstad, whom I appointed and who had, during his research work at CMI, established himself as one of the outstanding experts within powder mechanics internationally. I was then, in 1985, given the honourable status of a "Permanently Invited Guest" to this working party, with the right to take part in all its meetings and receive all papers concerning its activities.

My own research on powder mechanics started in 1969, when I conducted a simple, but useful investigation on the relationships between bulk density and angle of repose of fish meals, and the size, shape and surface stickiness of the particles in the powder. This work was conducted in cooperation with the Norwegian Research Institute for the Fish Oil and Fish Meal Industry (Ref. 34).

In 1972 I initiated a long-term research programme, backed by NTNF, in the area of storage and flow of powders in silos, together with my co-workers Per-Gunnar Leversen and Gisle G. Enstad. I was able to obtain a Jenike shear cell for the determination of specific powder mechanical properties of powders, and I conducted myself the first series of experiments (Report 3). During this

period I also first established contact with Dr. A.W. Jenike in USA, the "grand old man" in the field, with whom we stayed in contact for many years. I was first introduced to Dr. Jenike by one of the pioneers of powder mechanics in Norway, Mr. William Bruff. In addition to the basic research in powder mechanics, CMI through the years carried out a large number of design projects related to storage and flow of powders in silos etc., in a wide spectrum of Scandinavian industry. For my own part these research activities resulted in two publications in international journals (Ref. 35 and 36), and a more applied paper in a Norwegian journal (Ref. 37). Per-Gunnar Leversen's Ph.D. degree on pneumatic transport of powders, and Gisle Enstad's dr. techn. degree and important publications on the theory of powder mechanics, were results of CMI's research during this period.

Finally, it should be mentioned that I, as a member of the EFChE Working Party of the Mechanics of Particulate Solids formulated the topic for, and initiated the planning of the two large international powder technology conferences in Bergen, viz. "In-Stream Measurements of Particulate Solid Properties" in 1978, and "Reliable Flow of Particulate Solids", in 1985.

4.8 Sectioning of Particle Packings, Dispersion and Mixing of Powders, Powders in Pharmaceutical Industry

Transformation of the two-dimensional information about the particle size distribution, which is found in a plane cut through a three-dimensional bed of particles, into the real particle size distribution in the bed, is essential in several branches of science, from mineralogy to biology. A survey of the literature showed that it had not been investigated whether the degree of regularity of the particle packing influenced the validity of the transformation theory that is normally used. Together with Gisle Enstad I conducted a study of this rather special problem, and the results were published in an international journal (Ref. 38).

Dispersion of powders, i.e. separation of the individual particles in a powder to such an extent that each particle is floating freely in a gas or a liquid, is of importance in many situations where powders and dusts are produced and handled. It was therefore not surprising that I was given the task, as part of my examination for the doctors degree at the Technical University of Norway, Trondheim in 1976, to give a lecture on the "dispersability of powders". The lecture was published as a "CMI-Beretning" (Ref. 39). Mixing of powders is another important aspect of powder technology, and this was the subject of my second compulsory lecture during the public examination for the doctors degree. This lecture was also published as a "CMI-Beretning" (Ref. 40). This very condensed account of the central problems of powder mixing was, in fact, the direct reason for the appointment of me as an external examiner for a doctors degree at Denmark's Pharmaceutical University, Copenhagen, in 1981. The topic of the thesis was mixing of powders in the production of drugs (tablets).

Powder technology in pharmaceutical production was the subject of a three-year research programme at CMI from 1977 to 1979, supported by NTNF and the six. main. main Norwegian pharmaceutical companies (Report 4). Central

problems were identification of relationships between particle properties and mechanical bulk properties of the powders involved, and the possibility of using electrostatic charging of particles for producing extremely homogeneous powder mixtures. Furthermore, work was conducted towards development of a fully instrumented tablet press. These investigations are described in a number of CMI-reports, authored by my co-workers, which will not be specifically mentioned here.

4.9 Powder Energy

Although "powder energy" never developed into a proper research programme at CMI, it should nevertheless be mentioned. The idea surfaced, inspired by ongoing research at Chalmers Technical University in Sweden, during the acute energy crisis during the first half of the 1970'ies. In this very special period even Volvo, the Swedish car producer, conducted serious investigations into the production of synthetic liquid petrol from solid biomass. Economic analyses had revealed, however, that the use of very fine wood dust as the fuel, rather than synthetic liquids, might present a considerable economic advantage. The idea was that wood dust, when injected into a car engine cylinder, can produce an explosion similar to the one produced by a mixture of petrol and air. It had been shown that per energy equivalent generated by combustion of the fuel, the production of fine wood dust would cost only one fourth of the production of a synthetic liquid fuel from biomass. This presented an opportunity for substantial investment in developing new technology based on powdered fuels. On the other hand it was appreciated that many obstacles had to be passed before a complete practicable solution was at hand. At CMI we were close to launching a three-year research programme in cooperation with Sweden and Denmark. The intention was to convert an old ship diesel engine to being run on wood dust. However, the programme never came into being, mainly because the energy crisis faded away. Clearly, during times where oil and gas can be purchased at comparatively low prices, such a programme is bound to be given low priority.

It is interesting to observe, though, that controlled burning of dust clouds (pulverized coal and bio mass) is being used to an increasing extent in thermal and electrical energy production.

4.10 Gas Explosions

As the "oil age" started in Norway during the 1970'ies, it became clear to me that the expertise that had been built up at CMI in the area of dust explosions presented a unique platform for starting up research into the hazards of gas explosions on oil and gas installations in the North Sea. I conducted a small literature-survey pre-project for the Norwegian state oil company, Statoil, during the autumn of 1976. (the report was submitted to Statoil either at the end of 1976 or early 1977). During 1977 the plans were laid for a two-year research programme sponsored by NTNF as part of the large SPS-programme, and by four oil companies, including Statoil. This research, executed during 1978 and 1979, prepared the ground for the subsequent very large and comprehensive seven-year gas explosion programme conducted by CMI from 1980 to 1986, supported by 6 major oil companies. Under the leadership of my successors at CMI/CMR this research was continued under new contracts for three more

periods, each of three years. The last contract so far terminates in 1995. The results from the important first two-year programme were presented in 1980 (Report 5). Due to work overload the publication of this work in the international open press did not occur until some years after (Ref. 41). The results showed, in a new and dramatic way, the decisive role of turbulence in determining whether a gas mixture will burn gently and slowly, or will produce a violent explosion. It is with the greatest indebtedness that I mention professor John H.S. Lee from Montreal in this context. After having identified him as one of the world's foremost gas explosion experts, I wrote to him and asked for his assistance in our research. He gave his positive reply immediately, and gave extensive help and inspiration in the first important phase of our research. Also my close co-worker Kjell Fuhre played a key role in the realization of the experimental programme. In 1980 I could appoint Dr. Bjorn H. Hjertager and involve him in the planning of the large 7-year research programme 1980-86. His unique theoretical expertise in turbulent combustion, turbulent flow and computer simulation of fluid dynamic processes added a most significant dimension to our own expertise. On the basis of my conviction that key persons of Dr. Hjertager's calibre must be given the necessary freedom to generate and conduct their own research, he was quite early in the seven-year gas explosion programme given the real responsibility and authority in the programme. My own active participation essentially terminated in 1980 (Ref. 42). However, when it became necessary, at a later stage, to put our gas explosion research into a wider risk analytical perspective, it became my task to do this (Report 6).

I should also like to mention that, as part of the big gas explosion research programme 1980-86, I carried the scientific and administrative responsibility for arranging an international seminar at the CMI concerning the possibility of using automatic suppression technology for fighting gas explosions on oil and gas installations offshore. The world's leading experts and suppliers of equipment were gathered, and a number of central scientific, technical and financial issues were discussed in detail (Reports 7 and 8).

However, gas explosion research not only consists in limiting the damaging effect of explosions that have already been initiated. It also indeed is a question of preventing ignition from occurring in the first place. It seems that there are still many problems to be solved in this area. We first conducted a preliminary investigation for the Swedish organization Brandforsk on the ignition of gases by metal sparks from impacts between solids (Report 9). This work was continued on behalf of the oil and gas industries. Subsequently we also conducted research on the auto-ignition temperature of gases and vapours. An investigation on the auto-ignition temperature of gas mixtures related to the North Sea activity is currently being published (Ref. 42a).

Via my membership in the Norwegian national committee NK31 (Electrical equipment in hazardous areas), I realized that basic knowledge of ignition and flame propagation in gases (and dusts) is essential for specifying adequate design criteria for safe electrical equipment and instrumentation to be located in areas containing explosive atmospheres. As part of my duties as a part time professor at the University of Bergen, I wrote a course of lectures on this subject (Report 10).

In 1992 I was asked to edit a special issue of the Journal of Loss Prevention in the Process Industries, dealing with process safety on offshore oil and gas installations, with special reference to the North Sea. This was a demanding, but also a rewarding task, and after some delay due to various circumstances beyond my control, the special issue (Vol. 7, No. 4) appeared in July 1994. Apart from the "editorial", which I devoted to focusing on the need for continued education and training in the various aspects of process safety, I wrote a paper, together with Odd Thomassen, Statoil, on potential ignition sources (Ref. 42b).

I also presented a paper, in another context, on new safety and environmental issues when moving from liquid fuels to natural gas (Ref. 42c).

4.11 Explosions in Sprays and Mists

In the context of oil and gas production in the North Sea, this topic is closely related to gas explosions both in theory and in practice. During spring of 1991 I carried out a fairly comprehensive literature survey comprising formation, ignition, combustion and explosion of sprays and mists of liquid fuels in air (Report. 11).

4.12 Venting of Dust Explosions under Real Process Conditions

It has already been pointed out that the earlier work on dust explosions at CMI was the starting point for developing our extensive research programmes on gas explosions. It is equally true that the gas explosion research has in turn added a new dimension to our dust explosion research. It gradually became clear to us that the degree of dust dispersion, the turbulence of the dust cloud, and the dust cloud concentration, in any real industrial situation, strongly influence the combustion rate of the dust cloud. These relationships had been known for some time from laboratory-scale experiments up to 1 m^3, but it had not been fully appreciated that they play a key role in explosions in industry. This fact has a particular impact on the process of venting of dust explosions in process equipment. At the CMI we quite early realized that the various relationships .involved are so complex that it would be necessary to conduct extensive full scale dust explosion experiments under realistic process conditions in various types of process equipment (Ref. 43).

We decided to conduct our first experiments in quite large scale. I first presented the idea late 1977, and started to organize an international multi-client programme, to be executed by CMI, including sponsors from UK, Sweden and Norway, in 1978. The programme was executed in 1981. Vaksdal Milling Plant near Bergen allowed us to use some old, partially condemned silo cells, each having a volume of 500 m^3.

This provided a unique possibility to generate realistic large scale venting data for silos. The first research programme was immediately succeeded by a further programme sponsored by the National Grain & Feed Association (NGFA) in USA. The results of these two programmes were presented at the International Loss Prevention Conference in Harrogate in 1983, and also published in an international journal (Ref. 44). In addition, a short summary was published for one of the main sponsors of the first programme, the Swedish Factory Inspectorate (Ref. 45). The discussion of the influence of turbulence on dust explosions in large silos was extended in a paper presented in Poland, which was subsequently published (Ref. 46). The experiments in the 500 m^3 silos ultimately generated higher explosion pressures than the silos could withstand, and they were completely destroyed. However, NGFA encouraged us to continue the research and financed the construction of a unique 22 m high silo of volume 236 m^3, designed for explosion pressures of up to 5 bars. A new comprehensive research programme for the American sponsors was executed, and the results were presented at the International Loss Prevention Conference in Cannes in 1986, and subsequently published in an international journal (Ref. 47).

Up to this point we had vented the explosion in the top of the silo, vertically upwards. NGFA now wanted us to investigate venting horizontally through a vent opening in the silo wall, close to the silo top. One experimental challenge was then to take care of the large horizontal reaction forces in such a way that the silo did not break down. This task was solved in an excellent way by my colleague Mr. Kjell Fuhre, who also supervised the the building up of the whole new silo explosion research facility outside Bergen. The silo wall-venting programme gave further interesting results, which were also published in an international journal (Ref. 48).

It gradually became clear to me that the design of adequate venting arrangements for dust explosions (as for gas explosions) may be regarded a risk-analytical problem. The existing literature on sizing of dust explosion vent openings was in part quite dogmatic, and I therefore found it appropriate to present some views on the risk analytical aspects, in three papers (Ref. 49, 50 and 51). I had, however, been aware of this aspect for a long time, and as early as in 1977 I presented some preliminary ideas during a conference in USA. (Ref. 52).

During 1986 I organized a further three-year (1987-89) dust explosion venting research programme at CMI, with a number of industrial companies and organizations in several European countries as sponsors. As a supplement to the large silo, a 5.8 m^3 bag filter was built, and the first extensive set of experiments was conducted. My co-worker at that time, Franz Alfert, played a central role in conducting these experiments. The results were presented at the conference on dust explosions in Nurnberg in Germany in 1988 (Ref. 53). The results show that for organic dusts, realistic aerodynamic conditions in a filter generate dust clouds that burn less violently than clouds of the same dusts generated by the classical German "VDI-method". However, for special, non-organic dusts, like silicon, quite violent explosions can result under certain circumstances.

In 1988 I also gave a paper in Poland, on the problem of scaling of vented dust explosions in silos (Ref. No. 54). In 1989 I presented a summary of new developments in dust explosion venting, at the "Loss Prevention" conference in Oslo. The paper was subsequently published in an international journal (Ref. 55).

In 1992 and 1993 I was invited to publish two further papers on dust explosion venting (Ref. 56 and 57).

5. POWDER TECHNOLOGY AT CMI FROM 1982-1988 AND THE TRANSFER TO PORSGRUNN, NORWAY

Up to 1982 I was heading the whole section of powder technology, dust and gas explosions at CMI. However, it was just not possible for me to contribute scientifically to all these fields to the extent required. As indicated in 4.10 and 4.11 above, I was heavily engaged in continuing the gas and dust explosion research at CMI and this absorbed most of my creativity and energy. Also the emphasis of my personal interests had moved towards these fields over time. It was therefore a privilege to have the opportunity to appoint Dr. Sunil R. de Silva to our powder technology group in 1982. He is a professional powder technologist with basic education and research experience both from Loughborough in UK and Karlsruhe and Clausthal in Germany. In addition he has considerable experience from industry. Together with Dr. Gisle G. Enstad, Dr. de Silva expanded CMI's powder technology research considerably during the years up to 1988. In particular I should like to mention the organization of POSTEC, which de Silva and Enstad established jointly, and which contributed significantly to the financing of CMI's powder technology research. However, in 1988 it was decided on a political level to move the powder technology activity from CMI to Porsgrunn in the eastern part of Norway. (Several years before this decision was taken, CMI was asked to contribute to the building up of a university-level course in powder technology at Porsgrunn. We decided to play an active role in this effort, but we made it clear that we were not in any case interested in having our research group moved to Porsgrunn.) After the move to Porsgrunn Dr. de Silva was appointed the first professor (II) of powder technology in Norway at the new centre for process technology education in Porsgrunn. Later also Gisle Enstad has been appointed professor (II) of powder technology there.

Although I should personally have enjoyed to see the powder technology research being continued in Bergen, it is a great satisfaction to experience that the field of research and education that I had the pleasure of introducing to Norway 25 years ago (Ref. 12), has now become part of our established university educational system.

6 EDUCATION IN PROCESS SAFETY TECHNOLOGY - THE NEW CHALLENGE

6.1 Teaching Activities

Right from the start of my professional career I have given lectures at conferences and seminars in Norway as well as in many other countries, including Sweden, Denmark, Germany, UK, Poland, USA, Canada and P.R. China. My contact with P.R. China for more than 10 years, which started in 1983, is special, also because of my status as visiting professor of Northeastern University in Shenyang. During my visits in China I have given comprehensive lecture courses extending over several days.

In Sweden I gave my first extensive course on dust explosions in 1979. The course was organized by the Swedish Association of Engineers, and was repeated in 1980, 1981 and 1982. Since 1992 I have visited Sweden twice a year to lecture on a seminar based on my book on dust explosions (see 6.2). These seminars are organized by the Swedish Fire Protection Association.

In 1992, 1993 and 1994 I lectured at an annual European summer school on dust explosion prevention and mitigation, arranged at Cambridge, UK. An edited version of my 1992 survey lecture was published in 1993 (Ref. 16a). An updated version of this paper was presented in China in 1994 (Ref. 16b), and an extended version of the China paper has been accepted for publication in an international journal (Ref. 16c).

In November 1994 I shall give a survey lecture on dust explosion hazards in the ferro-alloys industries, in USA (Ref. 16d).

Via my membership in the Norwegian national committee NK 31, (corresponding to the Technical Committees 31 of IEC and CENELEC) it has become clear to me that basic insight into processes of ignition of gases, vapours, mists and dusts is important for proper understanding of the performance of instrumentation and other electrical equipment designed for being used in industrial areas containing explosible atmospheres. When I was appointed part time professor of the University of Bergen in 1992, I therefore decided to give a course of lectures dealing with this particular topic. The course notes (Report 10) may perhaps appear as a students textbook by the beginning of 1995, published by Tapir in Trondheim. The course seems to gain increasing attention, and in addition to teaching it in Bergen, I also give it at the National College of Industrial Safety at Haugesund. It also seems as if the course may be of interest to students at the Engineering department of Bergen College, and there may be a possibility of developing a co-operative scheme between this college and the University of Bergen.

6.2 Textbook on Dust Explosions. International Awards.

The change of my position at CMI in 1988 from chief scientist to senior scientific advisor, gave me a unique opportunity to realize a dream that started to develop in my mind during 1987: to write a comprehensive textbook on dust explosions, based on my experience gained during more than 20 years of active research and consultancy for industry.

I obtained an agreement with Butterworths, UK early 1989, and after 18 months of hard work, the manuscript was submitted in July 1990. The book appeared in the book shops in July 1991. After about 2 years, most of the first edition had been sold, and the publisher (now: Butterworth-Heinemann) decided to publish the second edition as a paperback version, at a price that even students may afford(!) The paperback version was ready for release in July 1994.

This book no doubt constitutes a significant part of the basis for awarding me the "higher doctorate" D.Sc. (Eng.) at London University, and possibly also to the fact that I was awarded the W. Cybulski Medal by the Polish Academy of Science, for 1992.

The first extensive chapter of the book gives a broad, largely self-contained, overview of the whole problem complex, and recently it has been translated into Swedish and will soon be published in Sweden by the Swedish Fire Association as a separate volume.

During 1992/93 I translated some practical sections of the book into Norwegian and added some more material in co-operation with my colleague at CMR, Kees van Wingerden. The result is a handbook that may be useful to Scandinavian readers (Report 12).

7. SOME PERSONAL REFLECTIONS

By nature and temperament I am a typical experimentalist. I experience and understand the scientific reality primarily via pictures and analogies, rather than through the dry mathematical representation. It has therefore been my wish to work in environment having adequate experimental facilities, and at CMI I was given excellent opportunities for this. On the other hand, I fully realize that mathematics is the only possibility for establishing quantitative relationships. But sometimes I ask myself whether the mathematical formulation is the real truth, or whether it is only an abstract fit to experimental data. Nevertheless, I am convinced that mathematical descriptions of complex systems, will become steadily more important. Modern computer simulation techniques have opened huge possibilities for quantitative handling and treatment of extremely complex dynamic processes, within a wide spectrum of research areas in the domain of the natural sciences and technology. In that respect we are in the middle of a revolution. The large gas explosion research programmes conducted at CMI/CMR from 1980 is an excellent example. However, good experiments and

direct observation will always remain the basis for ensuring that the theoretical models provide acceptably accurate approximations to the reality they are supposed to simulate.

My work through more than 30 years at CMI/CMR confirms that my interest as a researcher is directed towards real problems in industry and the public domain. I feel attracted to problem-oriented applied research rather than to the very basics. Through the years I have become steadily more convinced that applied research can be just as good research as basic work. What determines the quality is the standards of logical structuring of the problems, and of analyzing results in a logical way. The question of whether the research has a clearly visible practical goal, or whether its relation to practice is less obvious, is of secondary importance.

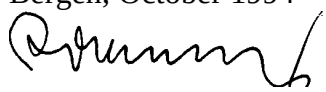
Contact across the borders between countries, and with the international research front has been essential for the development of the powder technology and explosion research at CMI. Through international working groups, presentation of papers at conferences and publication of papers in journals through many years, I have had the opportunity to establish a wide network of international contacts. In the first years the contacts were mostly to the powder technology environments, but in more recent years they have mainly been to expertise dealing with the fighting of dust and gas explosions and other thermal hazards in the process industries.

In addition to the contacts within European countries and North America, I should like to re-emphasize my close relations with China, which I visited for the first time in 1984. I made my fifth visit to this important country in August/September 1994 (Report 13).

Process safety technology is perhaps the most appropriate headline to cover the professional field that is now closest to my heart. This concept was probably first developed in Germany, with professor H.-G. Schecker in Dortmund as a central pioneer and authority.

I am a member of the advisory boards of the international journals Fire Safety Journal, Journal of Loss Prevention in the Process Industries, and Journal of Hazardous Materials.

Bergen, October 1994



Rolf K. Eckhoff

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