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IAEA CONFERENCE ON LARGE RADIATION SOURCES IN INDUSTRY (Warszawa 1959): WHICH TECHNOLOGIES OF RADIATION PROCESSING SURVIVED AND WHY?

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WARSZAWA

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IAEA Conference on Large Radiation Sources in Industry (Warszawa 1959): Which technologies of radiation processing survived and why?

The International Atomic Energy Agency (IAEA) - a United Nations Organization in Vienna, has organized in Warsaw an International Conference on "Large Radiation Sources in Industry" from 8 to 12 September 1959. Proceedings of the Conference have been published in two volumes of summary amount of 925 pages.

This report presents an analysis, which of the technologies presented at the Conference have survived and why. The analysis is interesting because already in the fifties practically full range of possibilities of radiation processing was explored, and partially implemented. Not many new *technologies were presented at the next IAEA Conferences on the same theme (Salzburg, 1963* and Munich 1969). Subsequent Conferences on the same topic were taken over by a series of International Meetings on Radiation Processing. The present one bears the number 11th and proceeds on March 14th to 19th in Melbourne, Australia.

The Warsaw Conference assembled a majority of the distinguished creators of radiation chemistry, with A.O. Allen, A. Charlesby, I. Draganic, A. Henglein, N.W. Holm, D.F. Schulte-Frohlinde and J. Silverman at the top. Already at the time of the Warsaw Conference an important role of economy of the technology was recognized. The present report selects the achievements of the Conference into two groups: the first concerns technologies which have not been implemented in the next decades and the second group which is the basis of highly profitable, unsubsidized commercial production. The criterion of belonging of a technology to the second group, is the value of the quotient of the cost of the ready, saleable product diminished by the cost of raw material before processing, to the expense of radiation processing, being the sum of irradiation cost and such operations as transportation of the object to and from the irradiation facility. Low value of the quotient, as compared to successful technologies is prophesying badly as concerns the future of the commercial proposal. A special position among objects of radiation processing is occupied by radiation processing technologies directed towards the protection or improving of the environment. Market economy does not apply here and the implementation has to be subsidized.

Konferencja Międzynarodowej Agencji Energii Atomowej na temat wielkich źródeł promieniowania w przemyśle (Warszawa 1959): które technologie przetrwały i dlaczego?

Międzynarodowa Agencja Energii Atomowej (IAEA), organizacja ONZ-owska w Wiedniu, zorganizowała w Warszawie w dniach 8-12 września 1959 r. międzynarodową konferencję na temat: „Wielkie Źródła Promieniowania w Przemyśle". Skupiła ona większość najwybitniejszych ówczesnych twórców chemii radiacyjnej. Uczestniczyli w niej m.in.: A.O. Allen, A. Charlesby, I. Draganic, A. Henglein, N.W. Holm, D.F. Schulte-Frohlinde czy J. Silverman. Prace Konferencji zostały opublikowane w dwóch tomach o łącznej objętości 925 stron.

Kolejne konferencje IAEA poświęcone zastosowaniom technologii radiacyjnych, które odbyły się w Salzburgu (1963) i Monachium (1969), przyniosły niewiele nowych idei w tej dziedzinie. Następne konferencje o tej tematyce zostały przejęte przez serię International

Meetings on Radiation Processing. Najbliższa, jedenasta, odbędzie się w Melburne, Australia, w dniach 14-19 marca 1999 r.

W raporcie dokonano analizy technologii zaprezentowanych podczas trwania Konferencji Warszawskiej. Analiza ta jest interesująca, gdyż już w latach 50-tych znane były możliwości zastosowań obróbki radiacyjnej, a niektóre były częściowo wdrożone. Już wówczas zauważono istotną rolę, jaką we wdrożeniach technologii odgrywa strona ekonomiczna proponowanego procesu.

Raport dzieli dorobek Konferencji na dwie grupy: pierwsza - dotyczy technologii, które nie zostały w następnych dziesięcioleciach wdrożone, analizując dlaczego - i drugą grupę, która jest podmiotem nadzwyczaj opłacalnej, niesubwencjonowanej produkcji komercyjnej.

Szansę na wdrożenie danej technologii można wstępnie określić przyjmując jako kryterium oceny wielkość ilorazu wartości sprzedażnej produktu, pomniejszonej o koszt materiału przed obróbką, do kosztów obróbki radiacyjnej, na którą składa się koszt napromieniowania i takich operacji, jak transport do - i - z zakładu napromieniowań. Mała wartość ilorazu, w porównaniu z technologiami opłacalnymi, daje niewielkie szanse na wdrożenie technologii.

Szczególną pozycję wśród obiektów obróbki radiacyjnej zajmują technologie radiacyjne skierowane na ochronę lub ulepszanie środowiska. Prawa rynku nie odnoszą się do nich, a ich wdrożenie musi być subwencjonowane.

CONTENTS

1. INTRODUCTION

The International Atomic Energy Agency Conference (IAEA) on "Large Radiation Sources in Industry", held in Warsaw, Poland in 1959 (September 8 to 12) may be considered as the 40 years old precursor of International Meetings on Radiation Processing. Proceedings of the Conference were published in two carefully edited and printed volumes, on almost one thousand (478+447) pages [1]. It was one of the first conferences and publications (STI/PUB/12) of the IAEA in the history of that organization, belonging to the United Nations. Problems of radiation chemistry and radiation processing were already mentioned during both Geneva Conferences on Peaceful Uses of Atomic Energy, (the first in 1955, the second in 1958), but the Warsaw Conference was entirely and in very details devoted to radiation chemistry and radiation processing.

Studying Proceedings of the Warsaw Conference on Large Radiation Sources in Industry, it is interesting to analyze which technologies of radiation processing survived and why? It was the question of survival, because practically all technologies proposed and considered at that time were already more or less extensively investigated and sometimes immediately implemented into commercial practice. Not very many really new proposals have been proposed during the following IAEA-conferences of that series: In Salzburg (May 27-31, 1963) entitled "Industrial Uses of Large Radiation Sources" [2], in Munich (August 18-22, 1969), under a little changed title "Large Radiation Sources for Industrial Processes" [3].

The Warsaw Conference has assembled prominent scientists who have influenced the development of the field during the next four decades. Just to name few of them in alphabetical order: A.O. Allen (Brookhaven National Laboratory), Milton Burton (Radiation Laboratory, University of Notre Dame, USA), A. Charlesby (Royal Military College, UK), H.C. Christensen (Atomic Energy Commission Risø), J. Dobo (Institute of Plastics, Hungary), I. Draganic (Yugoslavia), G. Földiak (Hungary), A. Henglein (Germany), N.W. Holm (Atomic Energy Commission Risø, Denmark), I. Kosa-Somogyi (Hungary), D.F. Schulte-Frohlinde (Germany), J. Silverman (USA).

The laboratory developments have been controlled by industry which does not implement technologies not confirmed by reasonable economic considerations. One group of technologies proposed during the Warsaw meeting and rejected for obvious reasons in the next years was connected directly with nuclear reactors and consisted in running radiation induced reactions directly in the core of so called chemonuclear reactor. Less controversial use of intensive radiation emitted by spent fuel elements (e.g. build in Australia by the AAECRE at the Lucas Heights, New South Wales), implemented for sterilization of raw wool, proved to be later impractical. Radiation induced chlorination reactions, of low and high molecular weight compounds, of promising energetics because of their chain character, did not find application because of difficulties in controlling them. The same fate met radiation processing of cheap materials like natural gas, coal, oil, rubber and food rich in water. On the other hand many technologies already presented in Warsaw survived in excellent shape. Starting with sources and their connection with nuclear industry, it was the production of cobalt 60 in useful forms, already well developed in Canada (Atomic Energy of Canada Limited, now Nordion) long before the Conference. Electron accelerators were also presented, not as an experiment, but already useful, technically mature application to crosslinking of polyethylene, supported by economic analysis of the technology. Killing of insects did not found wider popularity, but methods of stopping their proliference has still a modest application now. Sterilization of medical supplies of construction based on polymers was already 40 years ago a success.

One can say generally, that fulfillment of two conditions: (i) highly specific radiation induced effect and (ii) high value of the quotient of the value of radiation processed product to the cost of irradiation guarantee a commercial success.

The next IAEA Conferences on radiation chemistry and processing, as well as International Meetings on Radiation Processing series (first held in 1970) were more and more dealing with the application of radiation processing to waste of different kind, municipal or industrial. Usual rules of market economy could not apply to these technologies because they are not producing any goods and completely different economic approach had to be applied. The other values should be carefully considered, e.g. improving the environment and solving the question who will pay for expensive radiation.

Let us analyze some of the topics presented at the Warsaw Conference to realize why they have collapsed, to avoid reinventing them forty years later. The computer data bases do not reach deep enough. Chemical Abstracts, demanding personal scanning of indexes and volumes in libraries, are an old fashioned but extremely usefull exception. Our analysis may prevent starting new experiments on problems solved many decades ago that would otherwise mean waste of time. Our analysis considers also the discussion hold after papers, documented in the proceedings of the Warsaw Conference. It is a pity that such a custom is almost completely abandoned in the present - day conferences. Discussions revealed the way of thinking of the authors and participants on the floor.

2. RADIATION TECHNOLOGIES WHICH DID NOT SURVIVE THE PAST FORTY YEARS

As mentioned before, running of chemical reactions inside the core of reactors could not find acceptance even in view of the fact that at that time even the most risky nuclear operations were considered, like nuclear explosions serving to dig channels for peacefull purposes. Chemonuclear reactors seemed to be even riskier from the point of view of reactor technique. Radiation chemistry of fission fragments did not promise high radiation yields because of very high LET value of radiation. Synthesis of organic compounds tried in the Atomic Energy Research Establishment at Harwell, from a $CO+H_2$ mixture, with a G-value 0.3 was not attractive. Similarly low yields were obtained in gaseous reactions running over powdered nuclear fuel in l'Ecole Royale Militaire and l'Institute Interuniversitaire des Sciences Nucléaires in Belgium. Experiments on nitrogen fixation by reactor radiation conducted at the Rensselaer Polytechnic Institute, Troy, and Brookhaven National Laboratory, Long Island N.Y., USA were not promising, not speaking about the strange proposal to use, as the nuclear fuel, plutonium containig glass fibers! This study contributed to the knowledge of chemical physics of the nitrogen-oxygen system under ionizing radiation. Substantial means spent on these and similar projects are now understandable only in view of the enthusiasm and sympathy to the idea of "nuclear energy for peace".

The nuclear reactors (standard, experimental or energy producing ones, not "chemonuclear") were always examined as an indirect source of ionizing radiation and especially the practically costless radiation of spent fuel elements was attracting researchers. Important work was done at the Australian Atomic Energy Commission Research Establishment, Lucas Heights, where a facility for use of γ-radiation from spent fuel elements from the reactor HIFAR, similar to the British DIDO heavy water reactor. A careful investigation of the possibilities of the installation has shown advantages of using cheap radiation, but dramatic changes of energy and activity made application of precise dose to the object difficult. This conclusion has been reached later, after trial runs of large batches of variety of objects. As far as it is known, no installation exists nowadays in the world using spent fuel elements on a scale comparable to industrial Co-60 sources.

Cobalt-60 produced in dedicated nuclear reactors was considered already 40 years ago to be the best solution as a radiation source, but other isotopes were also considered. Beta-sources were treated theoretically by Silverman, but the idea was not realized on experimental scale. ^{137}Cs, a byproduct of the separation of spent fuel constituents, was already forty years ago considered as a cheap source of γ-radiation, although of lower energy than that from cobalt-60. The idea was coming back several times in the next decades, but dangers connected with high water solubility of all caesium compounds did not allow to construct large radiation sources and this isotope is still stored as the unpleasent waste of nuclear industry. Recently, some small, laboratory dry sources have been commercially constructed for the irradiation of blood.

Russian workers, of non disclosed affiliation, have presented blue prints for a nuclear reactor loop (called by the translator a "contour"), filled with an indium-gallium alloy. These metals were activated in the core and pumped in to an irradiation chamber. A 2 MW reactor was supposed to deliver in such a way an activity of ca 20 kCi gammas. As far as it is known, the idea was never realized, which is understandable, because such an activity in the shape of cobalt-60 is installed now in small laboratory sources standing in standard laboratories. The activity is 2-3 orders of magnitude lower than demanded by industrial installations.

A number of papers were devoted to radiation initiated synthesis of organic compounds, in particular containing chlorine. Researchers were tempted by high radiation yields, caused by chain reaction mechanisms of involved reactions. These papers remained in our memory as a contribution to the basics of radiation chemistry, but did not find wider application, because of wrongly chosen systems. Radiation chemists were concentrating on mass products of the chemical industry but did not consider that the expected production quotas are not compatible with the possibilities of radiation sources. Thus, the group of radiation chemists from the AERE Wantage Radiation Laboratory, Berks, U.K., made a wrong choice of production of the insecticide "Gammexane" (1,2,3,4,5,6-hexachlorocyclohexane) with participation of ^{60}Co gamma radiation. The gamma isomer (reflected in the trade name) was specially interesting from the point of view of application; its yield, reached in ionizing radiation initiation, was only slightly higher than that obtained by UV illumination. Probably the starting point of the chain reaction was similar. The proposed technology was never applied, even on a small scale.

Another proposal of radiation induced chlorination came from Institute Français du Pétrole and concerned aliphatic acids, mainly propionic acid. In spite of reaching radiation yields of $G = 10^5$ no industrial application has been obtained.

Researchers in Diamond Alkali Company in Ohio have chosen toluene and butyric acid as objects of radiation induced chlorination. Also in that system the products of photochemical and high energy radiation were similar, but initiation by γ-radiation was much more expensive. Conclusion presented by the author is very definite one: "the future use of large radiation sources for chlorination reactions depend upon, and still awaits, the development of unique applications and product". This conclusion was supported by the discussion, with one exception, when the opinion was expressed that in Germany a higher yield of the expected isomer was reached. This observation was never supported by published results and therefore one can accept that the opinion expressed at the end of the session devoted to radiation induced chlorination is valid also now.

Russian workers from the Karpov Institute in Moscow have investigated radiation induced oxidation of benzene by oxygen. Benzen alone is rather resistant to radiation like other aromatic compounds, therefore the authors have chosen aqueous solutions, in which reactions are starting from water derived radicals. The technology was not implemented because the solubility of aromatic compounds in water is low, and the spectrum of products very wide, including undefined, tar-like polymers.

Applications of radiation processing of polymers are numerable and those which bring profit are treated in the next chapter. In the present chapter one has to draw attention to the surface modification of polymers, i.e. radiation induced grafting. The idea seemed at that time very attractive, because it was able to change hydrophilic fabrics or films into hydrophobic at the outside, or vice versa. The Warsaw Conference revealed many such combinations, e.g. polymerization of vinyl acetate, vinyl alcohol, methacrylic acid to hydrophilic polymers, and styrene, acrylonitryle, dimethylsiloxane. That kind of polymerization has contributed to the general knowledge, but did not find realization in technology. Technological realization in the radiation field would be very difficult. Some hopes were connected with realization in the post-effect, i.e. in creation of free radicals in the polymer to be surface grafted, and dipping it in the monomer, or monomer solution. As far as it is known, the technology does not play any important role.

The Warsaw Conference contributed to the question of improving catalysts by ionizing radiation, especially by neutrons able to knock out atoms from the lattice, thus changing the catalytic activity. A collective paper by John Turkevich from the Princeton University in the USA presented results involving such modern (at that time) methods of characterization of the solid state like electron paramagnetic (spin) resonance (EPR according to IUPAC suggestion, or sometimes abbreviated as ESR) and model catalytic reactions like ortho-para hydrogen conversion. The catalysts chosen are rather strange from the present point of view: zinc oxide, zinc sulfide, phosphorus, activated by copper and chair coal. The paper needs a more detailed analysis, which is now difficult to perform in view of insufficient documentation and experimental methods being refined in next decades. The author represents the view that "EPR shows that catalytically active materials have strongly inter-acting electrons. ...In order to produce a catalytic material by radiation of an insulator or semi-conductor for the hydrogen-deuterium exchange, the electrons so produced must be clustered either by massive irradiation or by irradiation and subsequent careful heating". These and similar observations contributed to the radiation chemistry of solid state, but as far as it is known did not lead to the production of better industrial catalysts. We are stating "As far as it is known", because the field of catalysts is always covered by secrecy.

The American group from the Oak Ridge National Laboratory, Tennessee, was also looking into the field of heterogenous catalysis. They have shown the complexity of the problem, illustrated by reverse influence of radiation in some cases: the activity of a ZnO catalyst for the hydrogenation of ethylene was reduced by radiation, whereas the activity for the H-D exchange was increased. The last named "model reaction" indicated an increase of activity of a γ-alumina catalyst after radiation treatment, and in an even higher degree increasing the activity of a silica catalyst. These authors were rather pessimistic about the application of radiation for improvement of catalysts, because most of the effects disappear on heating to the temperature range of most commercial processes (known at that time).

Radiation chemistry connected with polymers was already widely presented at the Warsaw Conference, but as usually, many proposals did not find implementation in the next decades.

Six Russian chemists from the Karpov Institute in Moscow have presented in two papers a proposal for radiation (^{60}Co) induced polymerization of ethylene. As in every organic system, radiation causes abstraction of hydrogen leading to the formation of compounds of higher but very dispersed molecular weight. Experiments were done on small samples of ethylene in the gas phase or in solutions in organic solvents. Results were not conclusive for performation of experiments on kilogram amounts. Taking into account a relatively enormous scale of production of conventionally polymerized ethylene, radiation produced polyethylene had no chance for implementation, especially because radiation produced polymer has inferior properties in comparison to commercial products of different types. These authors did not look into the mechanisms of reaction and could not answer questions about the participation of ionic or free radicals. That was the question, occupying discussions of polymer chemists forty years ago.

Comparatively a high number of rejected radiation technologies had in the next decades negative influence on the decissions of implementation, especially in countries of controlled economy. It did not affect the implementations in countries of market economy, as one can see from the next chapter below.

3. PAPERS WHICH HAVE FOUNDED NEW TRENDS IN RADIATION RESEARCH AND TECHNOLOGIES OF RADIATION PROCESSING

The Warsaw Conference witnessed reports on basic radiation induced reactions which have shaped radiation processing techniques in radiation chemistry of polymers in next decades.

One of the papers in which M. Magat (later important contributor to basic and applied radiation chemistry) participated, from Laboratoire de Chimie Physique de la Faculté Sciences in Paris, reported about chain oxidation of hydrocarbons. Formation of diperoxides, e.g. in iso-octane, was observed. Simple, but precise kinetic considerations were discussed, which became a classic approach in radiation chemistry.

Also the next paper, but from Centre d'Etudes Nucléaires de Grenoble deals with radiation induced oxidation of hydrocarbons, formulating the square root of the dose rate law, valid in chain reactions. The authors operate easily with total G count, radical G count, length of the chain and energy of activation. All these physico-chemical aspects were already common tools of radiation chemistry and applied not only to radiation chemistry of organics but also of polymers. Sometimes there are forgotten nowadays.

Radiation induced polymerization was very attractive in the fifties, because of high radiation yields and existence of other methods of initiation which have to be compared with the new source of energy. The best known, at that time, radiation chemistry of water and aqueous solution directed many researchers to radiation induced polymerization of monomers in aqueous solutions. That was the case of four Japanese chemists from undisclosed affiliation (irradiations with γ from cobalt 60 of only 200 Ci activity, were made at the Kyoto University), on aqueous solutions of vinyl acetate. For reasons not quite clear, also the initiation with uranyl acetate among the additives was tried, apparently not because of their radioactive properties. Radiation induced polymerization in aqueous solution was later abandoned, but was started again in the next decades as the method of producing acrylic polymers of high absorption properties towards water. Interpretation of mechanisms of polymerization in aqueous solutions was comparatively simple because water was the main constituent of the mixture, absorbing therefore energy of radiation. All reactions were starting from the radicals produced by water radiolysis. At that time the hydrated electron was as yet not discovered, therefore the interpretation could not be complete or even true if pH of the solution was alkaline.

As concerns the radiation induced polymerization of monomers in nonaqueous solvents, there was a contribution from the Okamura group. The situation was not quite clear, because the basic radiation chemistry of solvents was not known yet so well as the radiation chemistry of water. The study of radiation induced reactions was supported by measurement of luminescence in the system. The effects of sensitation and protection were already known, e.g. manifested in the classic curve of nonaddivity of DPPH radical scavenging in the mixture of benzene and carbon tetrachloride of different proportions, as measured by the authors. Intensive fluorescence of pure benzene was falling down rapidly (quenched) with the addition of carbon tetrachloride. Similar effects were observed with other aromatic compounds, styrene and terphenyls. Temperature of irradiations was between room and -80°C, therefore some conclusions were taken as concerns the ionic or radical mechanisms.

Radiation induced polymerization, already developed forty years ago was not implemented immediately, but the knowledge has been used decades later with the idea and application of curing of solvent free paints in thin layers. Low energy accelerators were applied for these purposes, but the basic radiation chemistry remained the same.

Enormous work on radiation chemistry of polymers, done already in the fifties, was summarized at the Warsaw Conference by two prominent researchers, who were active for decades after the Conference. Milton Burton from the University of Notre Dame presented elementary processes after absorption of ionizing radiation, with a clear indication that all reactions start from the main constituent of the system, the fact sometimes forgotten even now by specialists being far from radiation chemistry. Effects of state of aggregation were clearly demonstrated with the consequences for technology, as well as characteristicts of kinetics, specific to radiation chemistry. The most important generalization of radiation chemistry and physics were presented by A. Charlesby, who was active in the field even in the nineties till his death in 1997. There is no need to summarize the knowledge he has demonstrated in Warsaw, because his papers and books have formed a continuous chain of achievements through decades.

Professor Charlesby recognized early the higher importance of radiation processing of commercial polymers rather than radiation induced polymerization. Indeed, already the Warsaw Conference has included an important paper by J.W. Ranftl (General Electric Company, Milwaukee, Wisconsin, USA) who revealed details of commercial radiation-crosslinking of polyethylene with the application of electron beam produced in an accelerator. He called it "a case study" because it involved not only the chemical aspects of the process but also the investments costs, including the capital cost of the machine, building and shielding costs, conveyor (or rewinding machine for films) and auxiliary equipment, then the operating costs which include the maintenance cost of equipment, labour costs of process attendants and power costs. Finally the analysis involved time efficiency of machine utilization and absorption efficiency of the product and process, and last but not least a return on the investment in the process. The electron accelerator was 2 MeV, a 10 kW generator of the resonant transformer type, costing $ 130,000 (1959 dollars) with an expected ten year amortization for a total life of 40,000 hours. It was estimated to deliver radiation equivalent to 1 MCi of cobalt 60. That activity impressed the participants of the Conference, because a 1 MCi cobalt 60 industrial source was not available yet at that time. The reported paper started, without any doubt, triumphal participation of electron accelerators in the field of radiation processing.

The paper by Ranftl did not reveal everything, and today we may observe that it reported not fully true information. The author stated honestly that it is difficult for him to answer questions and production quotas "as the companies involved were careful not to publish their production figures". He estimated that "at the end of 1959, the annual capacity on a continuous basis would be in the neighbourhood of 25 million pounds of polyethylene". However, his estimates were made on the basis of a 15 Mrad dose (150 kGy in todays units), which seems to be a low dose. The kind of polyethylene and its additives were not revealed. The cost of irradiation was in the order of cents per pound, exact figure was not revealed. In spite of the not full information, the paper presented the best economic analysis at the Conference. It was, and still is, a receipe for success.

Another success of radiation processing, i.e. the radiation sterilization of medical supplies was also fully presented at the Warsaw Conference. The main paper originated in Ethicon, Inc., Somerville, New Jersey, USA and was written by a leading figure in that field, Ch. Artandi, absent at the Conference, but represented by his collaborator W. Van Winkle, Jr. Radiation sterilization brought a revolution to pharmaceutical industry, being, along with gas sterilization, another method of "cold" sterilization. Another two types of accelerators (not a resonant machine mentioned above in connection with crosslinking of polyethylene) have been applied - Van de Graaff electron accelerator (2 or 3 MeV) and electron linac (7 MeV). The last one was found to be not stable enough. Indeed, later constructions were better and found larger application, because of higher range of electrons. Even now, linacs from some suppliers do not show a proper stability. The paper adviced the limits of the dose to 18 to 25 kGy (in present units) with the most popular dose of 15 kGy, satisfactory with average contamination of medical supplies made from polymers in automatic machines. It is clear that not very much has changed in that branch of radiation processing. The authors did not mention the cost of irradiation, claiming that in view of the high price of medical supplies, the expense for radiation was "negligible".

Other cases on killing undesirable forms of life, like insects, seemed at the first glance attractive but later were found to be inferior in comparison to chemical insecticides, or to simple biological methods like cooling of stored food. That was the case with grain and rice weevils (Calandra granaria L. and Oryzae L.) effectively killed by gamma radiation, as the paper from the Wantage Radiation Laboratory in Berks. U.K. has shown. There were similar approaches in next decades to the problem, but eventually fumigation and/or moderate cooling of grain in siloses proved to be better and cheaper.

The Warsaw Conference included for the first time the proposal of insect eradication by release of sterilized males. This technology is interesting even now, however of limited application, e.g. to isolated island, where some kinds of insects (those copulating only once) may be eliminated.

One has to mention also investigations on the induction of somatic mutations in plants. The changes are of course observed, but they are accidental and impossible to control. They are sometimes applied now, but are of marginal importance in present day practical genetics.

Economically acceptable radiation processing technologies have to follow the test of ratio of the value of the product to the cost of irradiation. The criterion of belonging a proposed technology to the acceptable group is the value of the quotient of the cost of the ready, saleable product, diminished by the cost of raw material before the processing, to the expense of radiation processing, being the sum of irradiation cost and such operations as transportation of the object to and from the irradiation facility. Low value of the quotient, as compared to successful technologies, prophesizes badly as concerns the future of commercial proposal. In the example of crosslinking of polethylene the raw material is cheap, but the value of crosslinked products is high, especially if the purpose of crosslinking is not only the increase of heat resistance, but the production of heat-shrinkable products of unique properties.

At the Warsaw Conference, radiation processing made for the purpose of environement protection did not exist yet. Market rules do not apply in that field, because these technologies do not produce any goods, but the cost of the process may be calculated easily. These expenses have to be compared with other, not involving radiation, technologies.

The Warsaw Conference involved discussion on standardization of elements of radiation processing, in particular of radiation sources. The discussion was moderated by the Polish Vice-president of the Polish Standards Committee, on behalf of the International Organization for Standardization (ISO). The conclusion were: there was a need to standardize the radiation sources, but it was necessary to proceed slowly and with caution to avoid creating difficulties for producers and users. Indeed, future developments did not show a proper activity of ISO. It was later the ASTM - American Society for Testing and Materials which has introduced standards of importance to the radiation processing. In the recent decade the standardization activities reversed the direction from ASTM back to ISO, which has accepted many ASTM standards verbatim as their own ISO-standards!

ASTM standards contribute very much to dosimetry. It is astonishing that dosimetry, an integral part of radiation processing, was treated at the Warsaw Conference only marginally. Even the two Geneva Conferences of Peaceful Uses of Atomic Energy (1955 and 1958), preceeding the Warsaw Conference, were dealing more with a high level dosimetry.

4. CONCLUSIONS

Analysis of topics presented and discussed during the Warsaw IAEA Conference gave almost full review of most important possible applications of radiation chemistry. However, it was not complete, because announcement of the preparation of the conference proceeded to all countries via government channels, thus not reaching industry and industrial research laboratories. The year of the Conference - 1959, is memorable in the history of radiation processing as the year of the annoucement of the development of heat shrinkable films and tubings by Raychem Corp. at Menlo Park, California. It is not clear if that Corporation new about the coming IAEA Conference; one can guess that even knowing it, authors of the idea and owners of highly promising technology were not ready to reveal details. The operation of controlled, precise blowing of heat shrinkable tubings to wider diameter is more complicated and expensive than the irradiation causing crosslinking.

The very beginnings of signaled new technologies by the International Atomic Energy Conference, were not accompanied by new terminology. One can hardly find the term "radiation processing" in the Proceedings. Indeed, the unit operation of radiation processing as we know it and making a use from it now, had different names. The excellent McGraw-Hill Yearbook of Science and Technology for the year 1971 calls it still "process radiation" and accordingly "process radiation facilities" etc. Neither of the three first IAEA Conferences had "radiation processing" in the title. Only the International Meetings on Radiation Processing established the term which describes the technology properly.

Looking at the first IAEA Warsaw Conference and next Conferences organized by that United Nations Organization and next Conferences on the same subject, but organized more frquently by industrial bodies, one has to ask about the future of these Conferences. The fundamental question about the necessity of conferences on the subject can be answered positively: they are necessary whoever takes care and means for the organization. To the participant of first three IAEA Conferences and number 3-10 IMRPs, sometimes as a vice-chairman, that answer is obvious. Analysis of the first, Warsaw Conference shows, that the majority of developed technologies was sponsored by governments of particular countries. The sponsorship was later more and more withdrawn, when particular productions were gaining sufficient ground in the market economy. The research and development as well as the implementation and transfer of technology were connected more and more with the industry. On the other hand, next conferences revealed more technologies which will never be directly selfsupporting, i.e. connected with ecology, protection of the environment and improving human health. The only connection of these technologies with the market proceeded via producers of sources of radiation. The question is, who is going to pay for the realization of complete projects and how the proposed technology compares from the financial point of view with no-radiation technologies giving similar results. Support of the International Atomic Energy Agency in such projects, at least organizational and representing the overnational and over-market point of view of the United Nations, is obvious.

5. REFERENCES

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