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Risø-M-2423

ACCELERATOR DEPARTMENT

Annual Progress Report

1 January - 31 December 1983

Abstract. A description is given of work in the fields of irradiation chemistry, physical dosimetry, radiation physics and technological application of radiation, radiation bacteriology research and irradiation technology, as well as of the operation of various irradiation facilities.

INIS-descriptors ACCELERATOR FACILITIES; BACTERIA; DOSEMETERS; DOSIMETRY; IRRADIATION DEVICES; RADIATION CHEMISTRY; RESEARCH PROGRAMS; RISØE NATIONAL LABORATORY.

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PREFACE

The objectives of the department are to conduct research in processes based on ionizing radiation and to contribute to its industrial utilization.

At our disposal there are several sources of ionizing radiation: electron accelerators at 10, 2, and 0.4 MeV and cobalt-60 facilities at 3 and 10 kCi. A new radiation source, a Multigas Laser EMG 102E, has been installed during 1983.

The major research effort is directed towards a better understanding of basic chemical processes and in particular the kinetics of these processes. The applied techniques include pulse- and steady-state radiolysis and computer simulation.

Proper measurement of absorbed dose is a prerequisite for application of radiation in research and industry. Research is conducted into the response mechanisms of dosimeters and in the development and calibration techniques of dosimeters for gamma and electron irradiations.

As radiation sterilization is one of the major industrial applications of radiation, the mechanisms leading to the destruction of microorganisms are a subject of the research program.

Commercial test irradiations can be carried out at all our radiation facilities, but only the 10 MeV electron accelerator is equipped for full-scale industrial purposes. Consultive and advisory assistance is rendered in connection with commercial irradiation, including e.g. calibration of a customer's dosimeter systems.

This report describes the principal activities in these fields for the period 1 January - 31 December 1983.

The contributions marked * are abstracts of published papers.

1. RADIATION CHEMISTRY

1.1 A pulse radiolytic study of the reaction $\text{OH} + \text{O}_3$ in aqueous medium*

(K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart (Port Angeles, WA, USA))

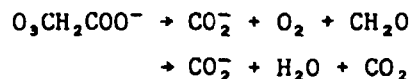
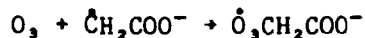
In slightly alkaline solution the ozonide radical ion, O_3^- , forms as the product of the hydroxyl radical reaction with ozone. For each O_3^- formed, two O_3 molecules are consumed. In acid solution the product of this reaction is the perhydroxyl radical, HO_2 , formed from one O_3 molecule. Our results are consistent with the gas phase reaction where the products are HO_2 and O_2 . A rate constant of $(1.1 \pm 0.2) \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ is found for the reaction, $\text{OH} + \text{O}_3 \rightarrow \text{HO}_2 + \text{O}_2$. This rate constant was obtained by three systems, build-up of O_3^- in basic solutions, by competition of the OH radical with the carbonate ion, and directly by O_3 consumption in acid solution. The rate constant for the reaction of HO_2 with O_3 is very low, $< 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. At $\text{pH} \geq 1$, HO_2 reacts with O_3 preferentially in its dissociated form, O_2^- . No spectroscopic evidence has been found for the HO , and HO_2 free radical intermediates.

1.2 Pulse radiolysis of the acetate-ozone system

(K. Sehested, J. Holcman and E.J. Hart (Port Angeles, WAS, USA))

Acetate is often used as a stabilizer for ozone in aqueous solution to diminish the rate of the autooxydation. The mechanism for the stabilizing effect of acetate as well as for the autooxydation is not well understood. The acetate has also been employed in the determination of the OH rate constant with ozone. A rate constant 30 times higher than the actual rate was determined, proving that the mechanism is different from that assumed earlier. Experiments at pH 9-10 show that the ozonide radical ion is formed as a product from the reaction of the acetate radical with ozone. The build-up at 430 nm is proportional to the ozone concentration yielding a rate constant of $7-8 \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. From the kinetics of absorption changes at 350 (the acetate radical and O_3^-) it is concluded that the reaction takes place in two steps. It is assumed that the first step is an addition of ozone to the acetate radical, in analogy with the acetate radical reaction with oxygen, followed by a fast bond break to CO_2^- and other products. The formation of O_3^- is

the product of CO_2^- reacting with ozone by electron transfer. The rate constant of the first step, the addition, is $1-2 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. Two molecules of ozone are consumed for each O_3^- formed. The following mechanism is suggested:



Oxygen inhibits the O_3^- formation because the acetate radical reacts fast ($3 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$) with O_2 forming a relatively inert peroxy radical.

At pH 7, buffered solution or at lower pH unbuffered, O_3^- is not observed as it undergoes a fast protonation to OH either by the buffer or by protons. The ozone absorption measured at 260 nm exhibits a drastic decrease, consistent with a chain destruction. As the acetate radical reacts with ozone the OH radical is formed, which subsequently reacts with another acetate molecule reforming the acetate radical, thus propagating the chain. As the ozone concentration decreases, the oxygen builds up and starts to compete with ozone for the acetate radical. The acetate peroxy radical will then tend to terminate the chain reaction.

1.3 Irradiation of acid ozone solutions with ^{60}Co - γ and electrons

(K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, (Port Angeles, WA, USA)).

Acid ozone solutions were irradiated by ^{60}Co - γ and electron pulses. The $G(-\text{O}_3)$ was determined under various conditions. The ozone concentration was varied from 25 - 400 μM , the pH from 1-6, the dose in ^{60}Co - γ irradiated from 45 to 1000 rd and with electron pulses from 0.5 to 4 krd in 0.5 - 4 μs . The solutions were either N_2O or Ar saturated; various amounts of oxygen and in special cases hydrogen were added in separate experiments. The $G(-\text{O}_3)$ measured varied from a few units in the electron irradiations to several hundred in γ -irradiations at very low doses. Stepwise γ -irradiations were also used and indicated an induction period for the ozone decomposition. There are indications of a difference between eluted and bubbled ozone, which probably can

be ascribed to impurities from the ozonizer. In certain cases H_2O_2 was determined in the irradiated solutions after the residual ozone was expelled.

Computer simulations of the reaction mechanism show fair agreement with experiments at low pH, but rather poor agreement at $pH > 3$.

1.4 Formation of ozone in the reaction of OH with O_3^- and the decay of the ozonide ion radical at pH 10-13*

(K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart (Port Angeles, WA, USA))

Ozone forms in aqueous alkaline solutions, pH 10-13, by a reaction between OH and O_3^- radicals. The reaction, $OH + O_3^- \rightarrow O_3 + OH^-$, is about 30% of the total reaction. A second is $OH + O_3^- + OH^- \rightarrow 2O_2 + H_2O$. The ozone formation is demonstrated by a high-pressure pulse radiolysis technique using a 4 μs , 40 krd pulse. The ozone rapidly disappears in a reaction with the simultaneously formed O_2^- reforming O_3^- . The product resulting from the O_3^- decay is the peroxy radical, O_2^- . The overall rate constant, $k(OH + O_3^-)$, is $(8.5 \pm 1.0) \times 10^9 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$. Computer simulations of the high-pressure system as well as of the atmospheric-pressure oxygenated system with high- and low-pulse intensity support a mechanism for the O_3^- decay based on the above-mentioned reactions. The protonation rate constant of the O_3^- radical ion, $k(O_3^- + H^+)$, is $(9.0 \pm 1.0) \times 10^{10} \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$.

1.5 Computer simulations of ozone decay in alkaline solutions

(J. Holcman, K. Sehested and E. Bjergbakke)

After determining the rate constants of $O_3 +$ radical reactions, relevant for the OH^- catalyzed decomposition of aqueous ozone, an attempt was made to simulate this process in the computer. It appears that literature data concerning the initiation kinetics, $OH^- + O_3$, $k = 50-70 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$, as well as overall decay kinetics, $k = 500-700 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$, do not yield satisfactory computer fits over the pH range 9-13. From the calculations it follows that due to high reactivity of the chain propagating radicals with O_3 , the literature value of the initiation rate constant seems too high. It is also found that detailed knowledge of the stoichiometry of the chain initiating step is essential for formulating a satisfactory mechanism.

It is concluded that new data from stopped-flow experiments are needed, partly in order to clarify questions about the chain initiation kinetics and stoichiometry, and partly because essential experimental parameters in the literature data have not been specified nor controlled.

1.6 Reaction of the carbonate radical ion

(J. Holcman and K. Sehested)

Literature values for the rate constant of the bimolecular reaction of the carbonate radical ion, $\text{CO}_3^- + \text{CO}_3^-$, are scattered (1×10^7 to $7 \times 10^7 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$). Different values are given for various pH's. Performing pulse radiolysis of carbonate/bicarbonate solutions at constant ionic strength, the rate constant $k(\text{CO}_3^- + \text{CO}_3^-)$ was found as pH independent. Different mechanisms have been suggested for this reaction, but neither of them has been conclusively proved, especially because a product of this reaction has neither been detected nor identified. Using high dose rate accelerator irradiation rather than γ -irradiation we find a product that oxidizes Fe^{++} analogous to H_2O_2 with a G-value closely corresponding to the reaction $\text{CO}_3^- + \text{CO}_3^-$. Further investigations are in progress in order to identify this product.

1.7 Dismutation of O_2^- by superoxide dismutase (SOD) in the presence of increased O_2 concentrations

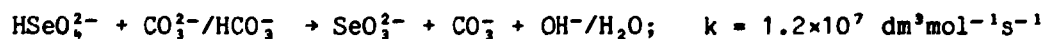
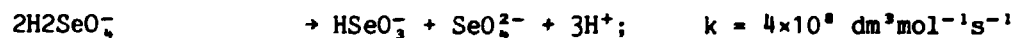
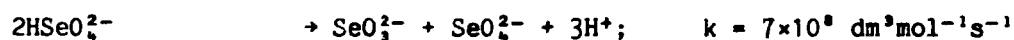
(J. Holcman and E. Bjergbakke)

Toxicity of oxygen in biological systems is often explained by a failure in O_2^- dismutation by the SOD enzyme. Preliminary investigations of the SOD activity in the pressure cell with oxygen concentrations up to 0.2 mol dm^{-3} show no influence of oxygen concentration on the kinetics of the O_2^- decay. This result indicates that the O_2^- dismutation by the SOD relies on a formation of the SOD- O_2^- complex rather than on the consecutive reduction-oxidation process.

1.8 Pulse radiolysis of oxoanions of main group elements. III Oxoanions of selenium and tellurium

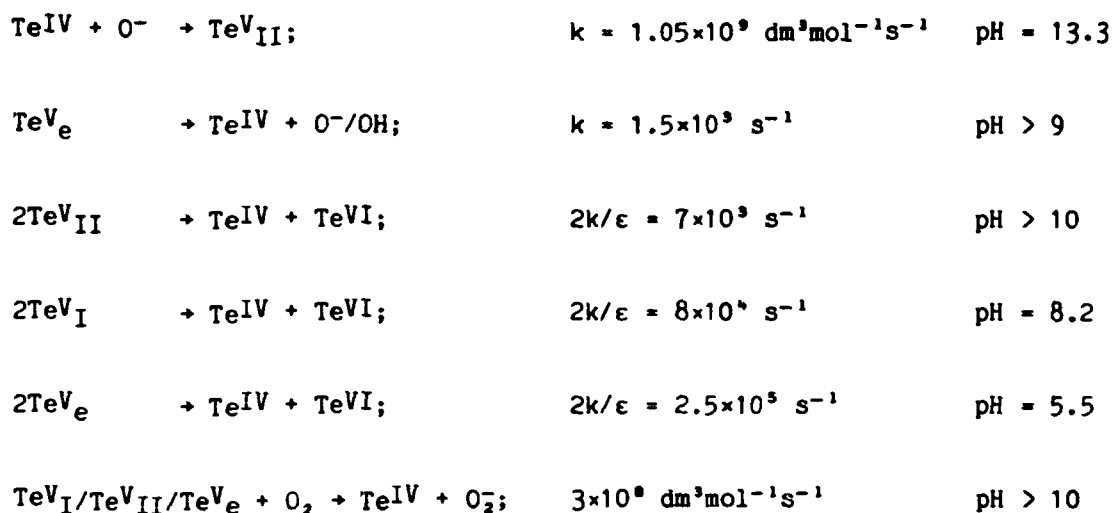
(U.K. Kläning (Institute of Chemistry, Aarhus University) and K. Sehested)

Spectra and kinetics of the reactions of electron adducts of selenate and tellurate ions and of OH/O⁻ adducts of selenite and tellurite ions were measured. The electron adducts of selenate were found to be identical with the OH/O⁻ adducts of selenite at the same pH. Formation of the following Se^V species is postulated: H₂SeO₄²⁻, HSeO₄²⁻, and SeO₄²⁻. The kinetics of absorbance changes suggest the following reactions:



The OH adduct of the acid tellurite ion, Te^V_I, was found to be similar to the electron adduct of the tellurate ion, Te^V_e. The OH/O⁻ adduct of the tellurite ion, Te^V_{II}, in alkaline solution is the electron adduct of tellurate. No interconversion of Te^V_I and Te^V_{II} was observed. The observations may be rationalized by assuming that the acid tellurite ion like the tellurate ion is hexacoordinated to the ligand oxygen atoms and that the tellurite ion has the structure TeO₃²⁻.

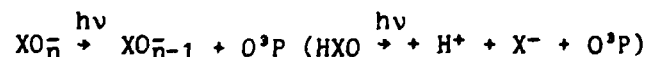
Measurements of kinetics of absorbance changes suggest the following reactions:



1.9 Ozone formation in laser flash photolysis of oxoacids and oxoanions of chlorine and bromine*

(U.K. Klänig (Institute of Chemistry, Aarhus University), K. Sehested, and Th. Wolff (University of Siegen, W. Germany))

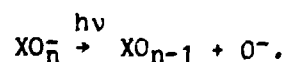
The kinetics of ozone formation in photolysis of O_2 -containing solutions of HClO , ClO^- , ClO_2^- , ClO_3^- , HBrO , BrO^- , and BrO_3^- was studied by laser flash photolysis and conventional flash photolysis. The assumption usually made that ozone is formed in the reaction $\text{O}^3\text{P} + \text{O}_2 \rightarrow \text{O}_3$ only, subsequent to the primary process



was found to be valid for solutions at pH < 10, but not for strongly alkaline solutions. The rate constants of the proposed reactions of O^3P with O_2 and BrO_3^- were found to be $(4.0 \pm 0.5) \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ and $1.5 \times 10^7 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$, respectively. The formation of ozone in strongly alkaline solutions can be accounted for by the additional processes



with rate constants in the range $5 \times 10^8 - 1.5 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ subsequent to $\text{O}^- + \text{O}_2 \rightleftharpoons \text{O}_3^-$ and the primary process

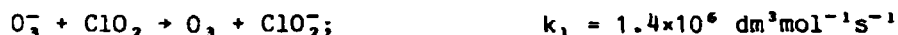


1.10 The reactions of chlorite with ozone and chlorine dioxide with the ozonide radical ion in aqueous solution.

Determination of the standard Gibbs energy of formation of the hydroxyl radical in aqueous solution

(U. Kläning (Institute of Chemistry, Aarhus University), J. Holcman, K. Sehested, and Th. Wolff (University of Siegen, W. Germany))

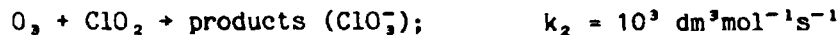
The ozonide radical ion, O_3^- , formed by pulse radiolysis of O_2 -containing alkaline solutions of ClO_2 , disappears in the reaction



The reverse reaction



was studied using a stop-flow technique. The reaction



could be neglected under our experimental conditions used for measuring the reverse reaction. From the rate of the reaction



and from the value of the acidity constant K of the hydroxyl radical equilibrium



we obtain the standard Gibbs energy of formation of the hydroxyl radical $\Delta G_{OH}^\circ = 19.5 \text{ kJ/mol}$ by using published values of ΔG° and the equation

$$\Delta G_{OH}^\circ = RT \ln(k_1 k_f K / k_{-1} k_b) + \Delta G_{ClO_2^-}^\circ + \Delta G_{O_3}^\circ - \Delta G_{O_2}^\circ = \Delta G_{ClO_2}^\circ \quad (5)$$

This value corresponds to 1.83 volt for the standard redox potential of the OH/OH^- couple.

1.11 The absorption spectrum and second-order decay of the hydrated electron in the temperature range 5-225°C

(H. Christensen (Studsvik Energiteknik AB, Sweden), and K. Sehested)

The high-temperature pulse radiolysis system has been used for investigating the hydrated electron at temperatures between 5 and 225°C. The maximum of the absorption band, λ_{\max} , is shifted to higher wavelengths with increasing temperature according to the equation

$$E_{\max}(T) = E_{\max}(20) + (T-20) \times k$$

where E_{\max} is the energy (in eV) at λ_{\max} . The value of k was determined to be 2.4×10^{-3} eV/°C.

The second-order rate of disappearance, $2k/\epsilon l$, of the hydrated electron



was determined in the same temperature range.

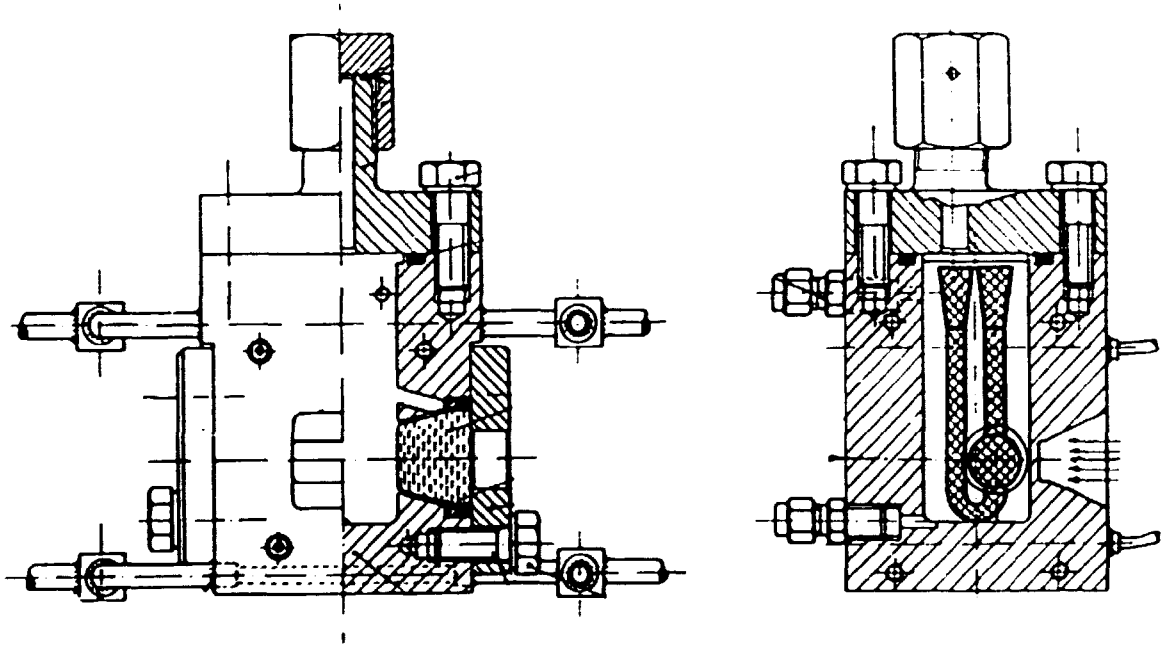
The optical density ($G \times \epsilon$) at λ_{\max} increases slightly with temperature. Presently, it is not possible to differentiate between an increase in G or in ϵ .

Assuming ϵ to be independent of temperature, k is determined as function of the temperature, and an activation energy, E_A , can be calculated. Presently a tentative value of $E_A = 5.5$ kJ/mole is obtained. This value agrees with those in the literature, determined at low temperatures.

1.12 High temperature-pressure-cell

(E. Engholm Larsen and K. Sehested)

With our four-year-old temp-pressure-cell it has been possible to perform experiments at pressures of up to 14 MPa and temperatures to 225°C. The main problems have been cracking of the 20 mm optical windows and temperature destruction of the neopren gaskets tightening the windows. A new construction of this part of the cell has been made. Dummy experiments have shown that the new construction is able to stand several recycles of temperatures up to 275°C at pressures of 15 MPa without leakage. It has also shown that single experiments can be performed up to 300 °C at 15 MPa by changing the gaskets



High-temperature pressure-cell.

inbetween the experiments. The new construction was finished at the end of the year and has been tested at temperatures of 250°C and pressures of 15 MPa with good performance. The idea behind the optical temp-press-cell is to be able to study radiation chemical reactions at temp-press conditions in nuclear reactors.

1.13 H-atom attack on methyl viologen in aqueous solution studied by pulse radiolysis*

(S. Solar and N. Getoff (Institut für Theoretische Chemie und Strahlenchemie der Universität Wien, Austria), W. Solar (Ludwig Boltzman Institut für Strahlenchemie, Wien, Austria), J. Holcman and K. Sehested)

Using hydrogen at high pressure up to 150 MPa ($0.12 \text{ mol dm}^{-3} \text{ H}_2$) as OH-scavenger in aqueous MV^{2+} solutions (pH = 1), it was possible to differentiate between two kinds of transients formed simultaneously by H-atom attack on methyl viologen. One of them was assigned to H-adducts on N-atom, $\dot{\text{M}}\text{V}^+\text{H}^+$, ($k = 3.5 \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$) with absorption bands identical with those of the radical cation, $\dot{\text{M}}\text{V}^+$, however, with $\epsilon_{392.5} = 3200 \text{ m}^2 \text{ mol}^{-1}$ and $\epsilon_{600} = 1100 \text{ m}^2 \text{ mol}^{-1}$. The $\dot{\text{M}}\text{V}^+\text{H}^+$ species deprotonate with $k = 2 \times 10^9 \text{ s}^{-1}$ forming the long-lived radical cation, $\dot{\text{M}}\text{V}^+$. The second type of transients produced with $k = 2.5 \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ was attributed to H-adducts on ring carbon, $\dot{\text{M}}\text{V}^{2+}\text{H}$ with $\epsilon_{310} = 700 \text{ m}^2 \text{ mol}^{-1}$ and $\epsilon_{470} = 1100 \text{ m}^2 \text{ mol}^{-1}$ decaying by second order with $2k = (6.0 \pm 1) \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. The formation of $\dot{\text{M}}\text{V}^+$ by electron transfer from 2-propanol radical was reinvestigated (pH = 0 to 7); its absorption spectrum did not change in this pH-range.

1.14 Reactivity of OH and O^- with aqueous methyl viologen MV^{2+}

(S. Solar and N. Getoff (Institut für Theoretische Chemie und Strahlenchemie der Universität Wien, Austria), W. Solar (Boltzman Institut für Strahlenchemie, Wien, Austria), J. Holcman and K. Sehested)

The OH radicals react with methyl viologen with $k = 2.3 \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. Although this rate constant is an order of magnitude lower than the typical rate for reaction of OH radicals with aromatic compounds, the only product detected has been ascribed to the OH-adduct on the ring carbon atoms of MV^{2+} ($\lambda_{\text{max}} = 470 \text{ nm}$ and $\epsilon_{470} = 2000 \pm 70 \text{ m}^2 \text{ mol}^{-1}$ calculated for full yield of OH radicals). In strong alkaline solutions, pH ≥ 13.8 , MV^{2+} was found to be stable at room temperature contrary to the literature data. No spectral

changes were found within 20 hours in $1 \text{ mol dm}^{-3} \text{ NaOH}$, $10^{-3} \text{ mol dm}^{-3} \text{ MV}^{2+}$ solutions, both aerated and deaerated. The O^- radical was found to react preferentially by H-atom abstraction from $-\text{CH}_2$ groups of MV^{2+} (80% of the total reaction $k = 1.2 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$). The radical thus formed has no absorption in the experimentally accessible spectral range, but is converted to a long-lived transient absorbing at 392.5 and 605 nm ($\epsilon_{392.5} = 3400 \text{ m}^2 \text{ mol}^{-1}$ and $\epsilon_{605} = 1600 \text{ m}^2 \text{ mol}^{-1}$). Due to lack of the absorption spectrum of this product and substantially higher rate constant of $\text{O}^- + \text{MV}^{2+}$ than for $\text{OH} + \text{MV}^{2+}$ it is not feasible to evaluate the amount of H-atom abstraction by the OH radical. The remaining 20% of O^- radicals form a transient ($k = 3 \times 10^8 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$) with $\lambda_{\text{max}} = 470 \text{ nm}$ and $\epsilon_{470} = 2200 \text{ m}^2 \text{ mol}^{-1}$, which is ascribed to an O^- adduct on the ring carbon of MV^{2+} . This radical is thought to be a conjugated base of the OH-adduct. Work is in progress to substantiate this hypothesis.

1.15 Computer simulations of the reactions in the Fricke dosimeter with varying Cl^- concentrations

(E. Bjergbakke)

This work is performed in collaboration with J. Swallow, Christie Hospital and Holt Radium Institute, Manchester, and B. Parsons, Kelterston College North E Wales Institute.

The work on the computer simulations of the reactions in the Fricke dosimeter was continued. The fit is still not perfect, and it is concluded that more experimental data are needed.

1.16 Contract work for Studsvik Energiteknik AB

(H. Christensen (Studsvik Energiteknik AB, Sweden), E. Bjergbakke, and O. Lang Rasmussen (Computer Installation))

The work consists of simulation of the radiation chemistry in connection with radioactive waste disposal and reactor chemistry.

1.17 CHEMSIMUL - a program package for numerical simulation of chemical reaction systems*

(O. Lang Rasmussen (Computer Installation) and E. Bjergbakke)

A description is given of a program package, CHEMSIMUL, for numerical simulation of chemical reaction systems. The main components in the package are a translator of chemical equations to differential equations, a balance equation program, a differential equation solver, EPISODE, and an input/output program. The performance of the program is demonstrated by four examples. A manual for the input file and the complete program text with comments are given in Appendices I and II.

1.18 References

K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, A Pulse Radiolytic study of the Reaction $\text{OH} + \text{O}_3$ in Aqueous Medium. Submitted: J. Phys. Chem.

K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, Formation of Ozone in the Reaction of OH with O_3^- and the Decay of the Ozonide Ion radical at pH 10-13. J. Phys. Chem. (Issue 88, 269, 1984).

U.K. Kläning, K. Sehested and Th. Wolff, Ozone Formation in Laser Flash Photolysis of Oxoacids and Oxoanions of Chlorine and Bromine. Submitted: Trans. Faraday.

S. Solar, W. Solar, N. Getoff, J. Holcman and K. Sehested, H-Atom Attack on Methyl Viologen in Aqueous Solution Studied by Pulse Radiolysis. Submitted: Trans. Faraday.

S. Solar, W. Solar, N. Getoff, J. Holcman and K. Sehested, Reactivity of OH and O^- with Aqueous Methyl Viologen MV^{2+} . Submitted: Trans. Faraday.

O. Lang Rasmussen and E. Bjergbakke, CHEMSIMUL - A Program Package for Numerical Simulation of Chemical Reaction Systems. (Risø-R-395, 1984).

2. RADIATION PHYSICS, PHYSICAL DOSIMETRY, AND TECHNOLOGICAL APPLICATION OF RADIATION

2.1 Experimental and calculated effectiveness of a radiochromic dye film in stopping 21 MeV ${}^7\text{Li}^-$ and 64 MeV ${}^{16}\text{O}$ ions

(J.W. Hansen and K.J. Olsen (Dept. of Radiophysics, University Hospital of Copenhagen, Herlev))

The relative radiation effectiveness of 21 MeV ${}^7\text{Li}^-$ and 64 MeV ${}^{16}\text{O}$ ions in being completely stopped in a tissue equivalent film dose meter has been measured as a function of penetration depth and energy, and the results have been compared with calculations based on a delta ray theory for heavy charged particles. The experiment was designed to test calculations particularly in the Bragg-peak region of the slowing down particles where significant deviation between theory and experiment was found. The theory is fundamentally based upon calculations of the radial distribution of dose around the particle track, and comparisons are made with published experimental and calculated results showing good agreement. Fitting of the $D_{0.7}$ dose and the size of the radiation sensitive element, $a_{0.7}$, in the detector does not improve the overall correlation between theory and experiment. It is concluded that disagreement between theoretical and experimental RE-values below 1.5 MeV/amu is due to lack of equivalence between the delta ray spectrum and the slowing down spectrum of electrons from low-LET radiation.

2.2 Predicting RE of alanine for high-LET radiation

(J.W. Hansen and K.J. Olsen (Dept. of Radiophysics, University Hospital of Copenhagen, Herlev))

Dose-response characteristics were measured for the crystalline amino acid alanine irradiated with beams of ${}^{60}\text{Co}$ γ -rays, 6 MeV and 16 MeV protons, 20 MeV α -particles, 21 MeV ${}^7\text{Li}^-$, 64 MeV ${}^{16}\text{O}^-$, and 80 MeV ${}^{32}\text{S}$ ions. The experimental radiation effectiveness RE with reference to low-LET radiation of ${}^{60}\text{Co}$ γ -rays was compared with theoretical RE-values derived from a model based on track structure theory. The ion beams covered an initial LET-range of 28-20201 MeVcm²/g and the experimental RE decreased with increasing LET being approximately 0.25 for the sulphur ions.

Due to time-dependent changes in sensitivity of the ESR spectrometer and a subsequent comprehensive repair, the experimental RE-values are not finally determined. Model calculations of the relative effectiveness have for a sensitive site size of $3 \cdot 10^{-7}$ cm shown values of 0.83, 0.99, 0.57, 0.37, 0.30, and 0.22 for the above mentioned heavy charged particles, respectively.

2.3 Investigations of the alanine dose meter

(J.W. Hansen, K.J. Olsen (Dept. of Radiophysics, University Hospital of Copenhagen, Herlev))

The dose measurements in the 160 MeV spread peak proton beam of the Harvard cyclotron accelerator (L. Verhey, Dept. of Radiation Medicine, Massachusetts General Hospital, Boston, USA) have not been finally evaluated. The aim of the work is to elucidate a discrepancy between measured relative biological effectiveness (RBE) of the proton beam in tissue and theoretical RBE values. Preliminary measurements and intercomparisons revealed a -7% divergence of our measurements from expected nominal values with a statistical spread of 2%. This deviation together with instability in our ESR spectrometer led to a long-time repair of the instrument (Varian E-3).

Irradiations with 7 MeV and 20 MeV electrons and 4 MV and 16 MV x-rays on the linear accelerators at Copenhagen University Hospital at Herlev have shown energy independency of alanine as compared with ^{60}Co γ -irradiations. The dose calibration performed at Herlev with an ion chamber embedded in perspex and compared with dose calibration performed with Fricke dosimetry showed agreement within the experimental uncertainty, at present 2.4% at a 95% confidence level.

Sensitivity investigations of alanine irradiated with 10 MeV electrons at Herlev and measured on a Bruker 100 D ESR spectrometer at the University of Aarhus have revealed a detection sensitivity of 0.2 Gy. By optimizing the ESR measurement procedure a threshold dose of 0.05 Gy is expected. Detecting a dose level of 1 Gy makes the alanine dosimeter possible as a tertiary standard in accordance with the Nordic Recommendation for External Beam Therapy for calibrating radiotherapy machines. The Danish State Institute for Radiation Hygiene is initiating investigations of alanine in cooperation with Herlev and Risø.

2.4 Basic concepts of radiation physics

(J.W. Hansen)

A chapter concerning radiation physics has been prepared for a text book "Techniques of Radiation Dosimetry" edited by K. Mahesh, D.R. Vij, and K.K. Nagpaul, Dept. of Physics, Kurukshetra University, India, to be issued by Wiley Eastern Ltd. Publishers and co-published by John Wiley and Sons, London. The main items of the chapter "Basic Concepts of Radiation Physics and Dosimetric Units" covers: properties of radiation fields, interaction of photons with matter, interaction of charged particles with matter, interaction of neutrons with matter, relative radiation effectiveness and quality factors, radiation detectors, radiation sources and radiation units and quantities.

2.5 Radiochromic dye film dosimeters

(A. Miller, W. Batsberg Pedersen (Chemistry Dept.), and W.L. McLaughlin (National Bureau of Standards, Washington, D.C., USA))

Thin film dosimeters are made from PVB containing the commercially available dye hexahydroxyethyl pararosaniline cyanide (P-15), or pararosaniline cyanide (P-15R) which is synthesized at the Chemistry Department at Risø. The P-15R dosimeter is very stable for long periods after irradiation, but it is very difficult to synthesize the dye, which has caused delays in the development of these dosimeters. The P-15R dosimeter is less light sensitive than the P-15 and the commercially available Nylon dosimeters. This work has in part been carried out under a research contract (2883/RB) with IAEA.

2.6 Lyoluminescence

(A. Miller)

Measurement of lyoluminescence of glutamine dissolved in water is used for dosimetry in the range of 100 Gy to 100 kGy. The precision of the measurements is now suitable for routine measurements ($< \pm 5\%$), e.g. for food irradiation. The system is being tested for application to electron beam irradiation.

2.7 Calorimetry

(A. Miller, W.L. McLaughlin (National Bureau of Standards, Washington, D.C. USA))

Calibration of the 10 MeV electron accelerator is made with water calorimeters, which are also used for routine dose setting. The calorimeters have been tested in intercomparisons with graphite calorimeters in collaboration with National Physical Laboratory, London, and National Bureau of Standards, Washington, D.C. Differences between dose readings with water and graphite calorimeters of the order of $\pm 5\%$ have been observed, but the differences seem to depend on irradiation conditions. More measurements are needed to resolve these discrepancies, but considering the simple nature of these calorimeters, better agreement may not be possible.

2.8 International activities

(A. Miller)

International activities are undertaken with the aim of improving high-dose measurements. We participate in a report committee under ICRU (International Committee for Radiation Units and Measurements), that is writing a report entitled "Dosimetry for Radiation Processing" which can be seen as a set of guidelines. We also participate in a coordinated research program under the IAEA for high-dose measurement, and in the implementation of a "Dose Assurance Service", first for gamma irradiation facilities, but now to be extended to electron beam facilities.

2.9 Commercially oriented activities

(A. Miller, W. Batsberg Pedersen (Chemistry Dept.))

Consultative assistance, test irradiations and industrial irradiations were carried out for Danish and foreign firms and institutions.

In order to improve the possibilities for commercial irradiations at the 10 MeV electron accelerator a new conveyor system has been ordered. It is expected to be able to handle product boxes with maximum size of $80 \times 60 \times 40 \text{ cm}^3$. Installation will take place during January 1984.

Dose measurements were carried out for Danish and foreign customers, using radiochromic dye film dosimeters. Calibrations of dosimeters were carried out using the reference gamma irradiation facility.

Measurements of radioactivity induced in products at 10 MeV electron irradiation were continued, but conclusions of these investigations have not yet been drawn.

2.10 References

J.W. Hansen, "Basic Concepts of Radiation Physics and Dosimetric Units". In: "Techniques of Radiation Dosimetry", (K. Mahesh, D.R. Vij and K.K. Nagpaul, eds.). Wiley Eastern Ltd. Publishers, and Wiley & Sons, London.

NPL Report RS(INT)72, October 1983, W.T. Morris "High-dose Intercomparisons in 10 MeV Electron Beams at National Physical Laboratory and Risø National Laboratory, May-June, 1982".

A. Miller, Dosimetry for Electron Beam Applications (Risø-M-2401, 1983).

3. RADIATION BACTERIOLOGY RESEARCH

Bacteriological research concerns the developing and testing of radiation sterilization processes, as well as advice and assistance on specific projects to prospective users of radiation sterilization. Research interests are concentrated on the mechanisms of radiation resistance.

3.1 W-reactivation in *Acinetobacter calcoaceticus*

(D. Berenstein)

Weigle(W)-reactivation has been demonstrated previously in *A. calcoaceticus* for the UV-irradiated lysogenic phage P78. This observation has been extended to a virulent phage HP2. Phage HP2 is also a subject for restriction and modification. The possibility of simultaneous induction of W-reaction and

modifying activity is being investigated.

3.2 Plasmid content of Acinetobacter strains

(D. Berenstein)

The presence of plasmids in 50 strains A. calcoaceticus obtained from Rigshospitalet, Copenhagen, is being investigated. The aim of this research is to discover a plasmid that could be useful as a cloning vector in A. calcoaceticus. The results suggest that a majority of the strains contain plasmids, but a completely satisfactory standard method for plasmid isolation in Acinetobacter has not yet been found. The strains have also been screened for phenotypic traits that could be conferred by plasmids: antibiotic and metal resistance, bacteriocin production, and radiation resistance. At present no correlations can be made between possession of a specific plasmid and any phenotypic marker.

3.3 Genetic mapping of A. calcoaceticus

(D. Berenstein)

The chromosome of an Acinetobacter strain Ac.78 is mobilized at a very low frequency by a plasmid pAV1. Attempts to increase the transfer frequency by incorporating transposons into the genome of Ac.78 have failed. More genetic crosses have to be performed before any linkage map of Ac.78 can be constructed.

3.4 Production and supply of microbiological standard preparations and biological indicators

(D. Berenstein)

The laboratory produced, supplied and assayed standard preparations of the spore former Bacillus cereus, strain C 1/1, as well as of the vegetative A. calcoaceticus, strain OA4. Tests of the microbiological efficiency of a Danish radiation facility was performed.

4. OPERATION AND MAINTENANCE OF IRRADIATION FACILITIES

4.1 HRC electron linear accelerator

(J. Fenger and B. Lynggård)

The accelerator has been in operation for a normal number of hours. About 65% of the time the facility was used for experimental irradiation, mostly in connection with the pulse radiolysis equipment. 30% of the time was used for service irradiation on the beam conveyor. Maintenance of the facility covered about 5% of the time. The following maintenance works were carried out:

Injector system: A set of light links to control the 250 kV injector were replaced after only half a year in operation; usually the lifetime is 2 years. The replacement takes place when the light transmission is reduced to 25% due to X-ray exposure. The light links were delivered from the usual U.S.A.-supplier and the firm has been informed about the problem.

The transformer oil in the high voltage tanks has been replaced (or regenerated) when the high-voltage properties were insufficient. A filter was installed in connection with the oil pump, and the transformer oil will be filtered every second year, whereby a longer lifetime of the oil is expected.

At several occasions there have been problems with the driver electronics for the 250 kV injector located inside the gun tank; some of the components were damaged, apparently without any reason. Lately some components designed close to the rated limits were replaced with more conservative components.

The injector was exposed to the atmosphere twice due to a malfunctioning gate valve; X-ray degradation of an organic seal was the main reason for the malfunction. To reprocess the injector takes approximately three weeks, and it is planned that the organic sealed valve will be replaced next year with an all-metal type.

Microwave system. A microwave coupler in the rectangular waveguide system had a vacuum leak and was replaced temporarily with an adapter on loan from Haimson Research Corporation. The leak was repaired in the Department, and after microwave testing at "Elektronikcentralen" the coupler was reinstalled. An adapter to replace the coupler in case of failure is under construction.

Beam scanning system (J. Poulsen). A new scanner system for the electron beam is under construction. In the new design a major part of the energy oscillates between magnetic flux in the scanner coil and electric charge on a capacitor bank controlled by a pulse-width-modulated switch mode system, thus reducing the power dissipated in the steering system. The new scanner will be fully transistorized.

4.2 Febetron, field-emission accelerator

The field-emission accelerator was used for pulse radiolysis of gases and for Raman spectroscopy. Due to a malfunction 5 modules were replaced.

4.3 ICT, low-energy accelerator

The low energy accelerator was used for dosimetry and polymerization experiments. The operation was trouble-free.

4.4 10,000 Ci ^{60}Co -facility

The 10,000 Ci ^{60}Co -facility was used for radiation research and for customer services. It further serves as a reference source for microbiological efficiency testing according to the IAEA's recommendations for the radiation sterilization of medical products. A motor-driven unit has substituted the manual container transport system.

4.5 5,000 Ci ^{60}Co -facility

The 5,000 Ci ^{60}Co -cell, presently located in the Control Department of the Danish Serum Institute, Copenhagen, was used for bacteriological research. A minor malfunction of the electronics has occurred.

4.6 3,000 Ci ^{60}Co -facility

The 3,000 Ci ^{60}Co -cell was used for research in radiation chemistry, radiation bacteriology, and customer services. The operation was trouble-free.

4.7 Lambda Physik Excimer Laser

(J. Fenger, E.E. Larsen, B. Lynggård, G. Hagen Olsen, K. Sehested, K.B. Hansen (Electronic Dept.), R. Wilbrandt (Chemistry Dept.), and U.K. Kläning (Institute of Chemistry, Aarhus University)).

The laser was delivered medio 1983 and will be used as a radiation source for Raman spectroscopy and flash photolysis at Risø and for ESR spectroscopy at Aarhus University. The laser was financed by an appropriation by Statens Naturvidenskabelige Forskningsråd (The Danish Natural Science Research Council). The installation was finished within the year and includes a frame special designed to be used in connection with the Febetron (Raman) and in connection with the flash photolysis set-up. Air outlet conduit and water cooling systems are provided. The Accelerator Department has been involved in testing of the laser during the installation at Aarhus University.

5. EXPERIMENTAL EQUIPMENT

5.1 Solid state detectors

(J. Fenger)

For the pulse-radiolysis detecting system two detectors have been chosen to cover the optical range from 600 - 1500 nm (3500 nm). A temporary set-up has been in experimental use with good performance.

5.2 Xenon lamp for laser flash photolysis set-up

(J. Fenger, E.E. Larsen, and K.B. Hansen, Electronic Dept.)

A complete analyzing light source based on a 150 W xenon lamp has been designed. The intensity pulser has been constructed in the Department and is

based on an already existing system. The lamp ignition system has been constructed in the Electronic Department. A lamp house for the xenon lamp was made, optical benches installed, and an old monochromator, Zeiss MM-17, was modified and used in the system.

5.3 Datamet

(B. Lynggård)

Two terminals, the PDP-8 computer installation and the text-processing computer, were connected to the Risø Datamet. Inter-communication programs were developed for the computers, and files from the central B7800 computer can now be listed on the lineprinter connected to the PDP-8 installation for fast hard copy records, or edited on the text-processing equipment and included as parts of reports.

5.4 Text-processing program

(B. Lynggård)

The Department has been involved in defining criteria for the program for the text-processing equipment so that it can operate properly on a printer with an extended character set (e.g. Greek letters, indexes and exponents), and so that special formats can be printed (e.g. nominator and denominator in fractions).

6. EDUCATIONAL ACTIVITIES AND PUBLICATIONS

6.1 Lectures

H. Christensen and E. Bjergbakke, Radiolysis of Concrete. 8th Nordic Radiation Research Society Meeting, Otnäs, Esbo, Finland, 30-31 August.

J. Holcman, K. Sehested, E. Bjergbakke and E.J. Hart, The O_2^- Radical Reactions in Neutral and Alkaline Solutions. 3rd International Conference on Oxygen Radicals in Chemistry and Biology. GSF Research Center, Neuherberg-

München, 10-15 July.

U. Kläning and K. Sehested, Radiolysis and Laser Flash Photolysis of Anions of Nonmetallic Elements. Argonne National Laboratory, Argonne, Illinois, USA, August.

A. Miller, Application of Dosimetry for Irradiation of Polymers. Åbo Akademi, Åbo, Finland, 28 August.

A. Miller, Dose Calibrations at Industrial Electron Accelerators. 8th Nordic Radiation Research Society Meeting, Otnäs, Esbo, Finland, 30-31 August.

A. Miller, Development of Thin Film Dosimetry for Electron Beam Application. IAEA Coordinated Research Program Meeting, München, 8-11 November.

Lectures at the 7th Danish-Polish Symposium on Radiation Chemistry, Swinoujście, Poland, 6-10 September:

E. Bjergbakke and H. Christensen, Radiolysis in Connection with Waste Disposal.

J.W. Hansen, Radiation Effectiveness of Heavy Ions.

J. Holcman and K. Sehested, Reactions of Ozone with the Radicals from Water Radiolysis.

A. Miller, Dosimetry by Means of Lyoluminescence of Glutamine.

K. Sehested and J. Holcman, Decay of the Ozonide Radical Ion.

6.2 Publications and Posters

Accelerator Department Annual Progress Report. 1 January - 31 December 1982. Risø-M-2389.

A.E. Buenfil-Burgos, R.M. Uribe, A. de la Piedad, W.L. McLaughlin, and A. Miller, Thin Plastic Radiochromic Dye Films as Ionizing Radiation Dosimeters. Radiat. Phys. Chem. 22, 325-332.

H. Christensen and K. Sehested, Reaction of Hydroxyl Radicals with Hydrogen at Elevated Temperatures. Determination of the Activation Energy. J. Phys. Chem. 87, 118.

H. Christensen and E. Bjergbakke, Radiolysis of Bentonite/Water Mixtures. Studsvik Technical Report NW-83/489.

H. Christensen and E. Bjergbakke, Radiolysis of Ground Water Under Methane at High Pressure. Studsvik Report NW-83/514.

H. Christensen and E. Bjergbakke, Radiolysis in Inclusions in Uranium Minerals. Studsvik Report NW-83/584.

H. Christensen and E. Bjergbakke, Radiolysis of Iodine in a BWR. Studsvik Report NW-83/609.

H. Christensen and E. Bjergbakke, Radiolysis of Groundwater From HLW Stored in Copper Canisters. Mat. Res. Soc. Symp. Proc. 15. Elsevier Science Publishing Co., Inc.

J.W. Hansen and K.J. Olsen, Relative Effectiveness of High-LET Radiation in a Tissue Equivalent Physical Detector. Proc. 11th Nordic Meeting on Clinical Physics, Vedbæk, 25-28 May.

J.W. Hansen (Poster), Medium Dose-Range Dosimetry by ESR Spectroscopy of Alanine. 11 Nordic Meeting on Clinical Physics, Vedbæk, 25-28 May.

J.W. Hansen and K.J. Olsen, Experimental Investigations of the Delta Ray Theory for Heavy Ions Applied to Thick Detectors. Proc. 7th International Congress of Radiation Research, Sessions E: Dosimetry, Radionuclides and Technology, E1-07, Amsterdam, Holland, 3-8 July.

E.J. Hart, K. Sehested and J. Holcman, Molar Absorptivities of Ultraviolet and Visible Bands of Ozone in Aqueous Solution. Proc. 7th International Congress of Radiation Research, Sessions A: Chemistry and Physics, A2-11, Amsterdam, Holland, 3-8 July.

E.J. Hart, K. Sehested and J. Holcman, Molar Absorptivities of Ultraviolet and Visible Bands of Ozone in Aqueous Solution. Analytical Chemistry 55, 46.

J. Holcman and K. Sehested, The Reaction of N,N-Dimethylaniline Radical in Strongly Alkaline Solution. Proc. 5th Symp. on Radiation Chemistry 1982, Siófok, 693-696.

J. Holcman, K. Sehested and E.J. Hart, Rate Constants and Product of the Reactions of e_{aq}^- , O_2^- , H and OH with Ozone in Aqueous Solutions. Proc. 7th International Congress of Radiation Research, Sessions A: Chemistry and Physics, A2-12, Amsterdam, Holland, 3-8 July.

W.L. McLaughlin, A. Miller and R.M. Uribe, Radiation Dosimetry for Quality Control of Food Preservation and Disinfestation. Radiat. Phys. Chem. 22, (1-2), 21-29).

W.L. McLaughlin, R.M. Uribe and A. Miller, Megagray Dosimetry (or Monitoring of Very Large Radiation Doses). Radiat. Phys. Chem. 22, 333-362.

A. Miller, Development of Thin Film Dosimetry for Electron Beam Application. Final Report, IAEA Contract 2883/RB (1 Aug. 1981 - 31 July 1983).

A. Miller, Thin Film Dosimetry for Electron Beam Applications. IAEA Contract 2883/R1/RB. Progress report for the period May-November 1982. Risø-I-118.

A. Miller, Dosimetry for Electron Beam Applications. Risø-M-2401.

A. Miller, K.H. Chadwick and J.W. Nam, Dose Assurance in Radiation Processing Plants. Radiat. Phys. Chem. 22, 31-40.

G. Nord, B. Pedersen, E. Bjergbakke, Dissociation and Dioxygen Formation in Hydroxide Solutions of Tris(2,2'-bipyridyl)Iron(III) and Tris(1,10-phenanthroline)Iron(III): Rates and Stoichiometry. J. Am. Chem. Soc. 105(7): 1913-9.

K.J. Olsen and J.W. Hansen, High-LET Dose Response Characteristics of the Dye Film Dose Meter in the Context of Track Structure Theory. Proc. of the 8th Symposium on Microdosimetry, Jülich, Federal Republic of Germany, 27 Sep.-1 Oct. 1982. Report EUR 8395 EN.

K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart, Formation of Ozone in the Reaction of OH with O_3^- and the Decay of the Ozonide Ion Radical. Proc. 7th International Congress of Radiation Research, Sessions A: Chemistry and Physics, A2-25, Amsterdam, Holland, 3-8 July.

K. Sehested, J. Holcman and E.J. Hart, Rate Constants and Products of the Reactions of e_{aq}^- , O_2^- , and H with Ozone in Aqueous Solutions. J. Phys. Chem. 87, 1951.

6.3 Test-irradiations

A/S Danfysik, Jyllinge
Danmarks tekniske Højskole
Danmarks farmaceutiske Højskole
Fibiger-Laboratoriet
Grindsted Products, Grindsted
Meda A/S, Herlev
Mialens, Tåstrup
Microtronic Aps, Roskilde
Mölnlycke A/S, Espergærde
A/S Nunc, Roskilde
Odense By & Amtssygehus
Radiflex ApS, Hedehusene
Sadolin & Holmblad A/S, København
Sankt Hans Hospital, Roskilde
Siemens, AG, München
Statens Seruminstitut, København
Axel Toft, Durup

6.4 Visiting scientists

H. Christensen, Studsvik Energiteknik AB, Nyköping, Sverige.
N. Getoff, Institut für Strahlenchemie, Vienna, Austria.
A.-M. Hansen, Statens Institut for Strålehygiejne, Copenhagen.
E.J. Hart, Port Angeles, WA., USA.
I. Janovský, Nuclear Research Institute, Rez, Czechoslovakia.
U. Kläning, Kemisk Institut, Århus Universitet, Århus.
W.L. McLaughlin, National Bureau of Standards, Washington, D.C., USA.
S. and W. Solar, Institut für Strahlenchemie, Vienna, Austria.
R. M. Uribe, Instituto de Fisica, UNAM, Mexico D.F.
Z.P. Zagorski, Institute of Nuclear Chemistry, Warszawa, Poland.

7. IRRADIATION FACILITIES AT THE ACCELERATOR DEPARTMENT

Electron Accelerators

1. Linear Electron Accelerator, Haimson Research Comp.

Model HRC-712

Specifications:

Electron energy 10 MeV
Average electron current 1 mA
Peak electron current at 10 MeV 1100 mA
Pulse length 0.01 - 4 μ s
Pulse repetition rates single pulses and
12.5, 25, 37.5, 50, 100, 150, and 200 pps.

Accelerator room beam facilities:

1. A bent beam with scan width of 60 cm in connection with a conveyor system provides a process irradiation capacity of 700 Mrd kg/hour.
2. Two horizontal beam ports, full average beam power, for electron and X-ray irradiation.
3. One horizontal beam port, reduced average beam power (12.5 pps) in connection with a $\pm 0.5\%$ beam slit.

Target room beam facilities:

1. Three horizontal beam ports, reduced average beam power (12.5 pps).

2. Field Emission Electron Accelerator, Febetron Model 705B

Specifications:

Electron energy 1.5 - 2.0 MeV
Peak electron current 4000 A
Pulse length 50 ns

3. Low-Energy Electron Accelerator, High Voltage Eng. Corp.

Model EPS 400-IND

Specifications:

Electron energy 400 keV

Electron current 50 mA

Scan width 120 cm

The accelerator is provided with conveyor to permit pilot-plant irradiation.

4. Excimer Laser, Lambda Physik Model ENG102 E1

Specifications:

Active medium	<u>F₂</u>	<u>ArF</u>	<u>KrCl</u>	<u>KrF</u>	<u>XeCl</u>	<u>N₂</u>	<u>XeF</u>	
Wavelength	157	193	222	249	308	337	351	nm
Pulse Energy (min)	10	200	30	250	150	7	100	mJ
Pulse width (FWHM)		14	9	16	10	6	14	ns
Single pulse and repetition rates								
up to	80	80	100	100	100	100	50	Hz

⁶⁰Co-Facilities

10,000 Ci ⁶⁰Co-facility (built at Risø 1957)

Designed for very homogeneous irradiation of samples with a maximum of 180, 100, or 60 mm. The corresponding maximum dose rates (6,400 Ci, 1 January 1984) are 3.9×10^5 , 1.1×10^6 , and 2.5×10^6 rd/h, respectively.

5,000 Ci ⁶⁰Co-facility (built at Risø 1971)

Designed for laboratory use and fitted with a 123 mm ϕ x 150 mm irradiation chamber. The dose rate in the center of the chamber (3,900 Ci, 1 January 1984) is 3.3×10^5 rd/h. The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

3,000 Ci ⁶⁰Co-cell (built at Risø 1968)

Designed for laboratory use and fitted with a 120 mm ϕ x 200 mm irradiation chamber. The dose rate in the center of the chamber (2,400 Ci, 1 January 1983) is 2.4×10^5 rd/h.

¹An appropriation by the Danish Natural Science Research Council, on shares with Aarhus University.

8. STAFF OF THE ACCELERATOR DEPARTMENT

Head : Knud Sehested

Office Staff: Ebba Haugaard and Ruth Madsen

Scientific Staff

Dvora Berenstein

Erling Bjergbakke

Jørgen Fenger

Johnny W. Hansen

Mogens Trier Hansen (left March 31)

Jerzy Holcman

Bent Lynggård

Arne Miller

Jørgen Poulsen (from September 19)

Technical Staff

Margit Elm Andersen

Karen Boysen

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Erik Engholm Larsen

Fritz Larsen

Inge Merete Larsen

Lauritz Nielsen (left February 14)

Gert Hagen Olsen

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Statens SerumInstitut, Copenhagen.

Dr. E.J. Hart, Port Angeles, WA., USA.

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<p>Abstract</p> <p>A description is given of work in the fields of radiation chemistry, physical dosimetry, radiation physics and technological application of radiation, radiation bacteriology research and irradiation technology, as well as of the operation of various irradiation facilities.</p> <p>Available on request from Risø Library, Risø National Laboratory (Risø Bibliotek), Forsøgsanlæg Risø), DK-4000 Roskilde, Denmark Telephone: (03) 37 12 12, ext. 2262. Telex: 43116</p>	<p>Group's own registration number(s)</p> <p>Copies to</p>