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ACCELERATOR DEPARTMENT
Annual Progress Report
1. January - 31. December 1981

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

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

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PREFACE

The objective of the Accelerator Department is to contribute to research, development, and the implementation of processes based on ionizing radiation; thus, the following activities are carried out:

- **Operation and maintenance of the irradiation facilities (three electron accelerators and three ^{60}Co-units).**
- **Radiation chemistry research of fundamental and applied problems in chemistry. The applied techniques include pulse- and steady-state radiolysis as well as computer simulation.**
- Radiation dosimetry research with respect to proper application of dose meters as well as to basic understanding of radiation absorption processes.
- Radiation bacteriology research mainly in relation to radiation sterilization problems and radiation-resistant microorganism, and also to increase basic knowledge of the radiation resistance mechanism. Production and supply of bacteriological standard preparations for control of irradiation sterilization plants.
- Development and construction of equipment for radiation experiments and for customer irradiation services. Upgrading of irradiation facilities.
- Customers services, including test and pilot irradiations, control and measurements, and advisory assistance.

The principal activities in these fields are described in this report which covers the period from 1. January to 31. December 1981. The contributions marked with \$ are abstracts of published articles.

1. OPERATION AND MAINTENANCE OF IRRADIATION FACILITIES

(J. Fenger and B. Lynggård)

1.1 HRC electron linear accelerator

The accelerator has been in operation for a normal number of hours. About 70 per cent of the facility is used for experimental irradiation, mostly in connection with pulse radiolysis equipment. Within the last year the service irradiation was extended to about 20 per cent. Maintanance of the facility covered about 10 per cent of the time. The following works have been carried out:

Injector system and beam-handling system: There have been problems with long-term intensity stability of the electron beam. During an eight-hour run the beam peak current may decrease by 30 per cent. A complete analysis of the system was carried out. The cathode of the electron gun was x-radiographed by the Metallurgy Department. No abnormalities were observed in the resulting very detailed pictures. The gun cathode is the original one and has logged 10,000 hours, life expectancy is in the range of 800 - 15,000 hours. A new gun cathode was purchased in 1981. By analyzing the beam-handling system the instability was traced to the electronics for the 90-degree bending magnet. The problem has been solved, but the electronics must be replaced. On tuning the beam optics by varying the magnetic field an increase of 5-10 per cent has been obtained in the beam current intensity.

The 210-kV high-voltage injector is controlled by fiber optics. The original glass light links were degraded by x-ray exposure, and plastic fibers ten times more resistant to x-ray were installed. After one month of operation with the new light links, an explosion occurred in the high voltage terminal. The light links and a high-voltage Lucite stand-off were destroyed. A temporary support for the high-voltage terminal was established and new light links were installed.

After two years of operation the beam output window on the 90-degree beam port was replaced due to a leak caused by deformation of the 0.5 mm aluminum window. The problem occurred due to insufficient water cooling of the window, but as there is no risk of an implosion of the window into the accelerator vacuum system, it was decided to replace the window once a year. The window is made of aluminum alloy AA 3003, which is an optimum material for the purpose.

Microwave system: The main thyratron in the high-voltage modulator failed after 4900 hours of operation. The spare thyratron was installed without problems. A new thyratron was delivered in December 1981.

Due to lack of power to drive the high-power klystron, the triode amplifier was replaced by the spare unit. Repair of the 2.8 GHz triode amplifier is now carried out in the Department. The klystron needs more and more input DC power for a constant microwave output power (15-MW peak power), and a replacement may be necessary within a year.

1.2 Febetron, field-emission accelerator

The field-emission accelerator was used for pulse radiolysis of gases and for tests during the installation of the Raman spectroscopy set-up. A general overhaul was completed at the beginning of the year and the operation has been troublefree.

1.3 ICT, low-energy accelerator

The low-energy accelerator was used for dosimetry experiments and for irradiation of lacquers. The operation has been troublefree.

1.4 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 new recorder was installed for documentation records, and the control system was redesigned for easier adjustment of the dose. A factor used for the dose calculation was changed by about 2 per cent, due to a change in the gearing of the system to 1:24.5 rather than 1:24 as expected earlier.

1.5 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.

1.6 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 mechanical radiation timers were replaced by an electronic timer with 0.01-minute resolution, corresponding to approx. 50 rads.

2. EXPERIMENTAL EQUIPMENT

2.1 Nanosecond gate for a 1P28 photomultiplier

(J. Fenger)

By pulse radiolysis experiments the high-intensity Cerenkov light, produced by the electron pulse, caused overload of the photomultiplier transient detector. To solve the problem a pulsing unit to gate the photomultiplier has been developed. During the gating period the sensitivity is reduced 10 times. Normal sensitivity recovers within 20 ns.

2.2 Pulse radiolysis experiments in the IR (infra red) region

(J. Fenger)

Pulse radiolysis experiments have been carried out in the wavelength region from 200 to 700 nm. An investigation in the IR region up to 1600 nm is initiated. The light source is the 150-W xenon lamp. Temporarily experiments have shown that the xenon lamp can successfully be intensity-pulsed in the IR region to yield an increase of 20 times at 1200 nm. The detector used is an InAs photodiode borrowed from Studsvik Energiteknik AB, Sweden.

2.3 PDP8-I computer installation

(B. Lynggård)

The background storage facility for the PDP8-I computer was extended to 3 disk units of 32 keywords and 2 magnetic tape units. The foreground storage capacity was extended to 8 kwords. These extensions make it possible to use the OS/8 monitor system and to compile Fortran programs.

Some programs were modified for the new system. A program was written that reads the output paper tape from a scintillation counter and compensates for background- and channel cross-counts.

3. RADIATION CHEMISTRY

3.1 Rate constants and products of the reactions of e^-_{aq}, O_2^-, and H with ozone in aqueous solutions

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

Ozonide ions, identified by their optical absorption band at 430 nm, are formed in electron-irradiated aqueous solutions by the reactions: $e^-_{aq} + O_3 \rightarrow O_3^-$ and $O_2^- + O_3 \rightarrow O_3^- + O_2$. Both reactions are quantitative and the rate constant for the first was determined in competition with oxygen to be $k(e^-_{aq} + O_3) = (3.60 \pm 0.20) \times 10^{10}\ dm^3 mol^{-1} s^{-1}$. The rate constant for the second, the peroxy radical reaction with ozone, was measured to be $k(O_2^- + O_3) = (1.52 \pm 0.10) \times 10^9\ dm^3 mol^{-1} s^{-1}$ from the pseudo-first-order build-up of the ozonide ions. The rate constant of the hydrogen atom reaction with ozone was measured in acid solution, pH 2, by competition with oxygen to be $k(H + O_3) = (3.65 \pm 0.20) \times 10^{10}\ dm^3 mol^{-1} s^{-1}$. The initial product is an OH radical.

3.2 Reaction of hydroxyl radicals with ozone

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

The OH radicals react rapidly with ozone ($k \sim 3 \times 10^9\ cm^3 mol^{-1} s^{-1}$) and some evidence for a new species (the adduct HO_4 or O_4^-) is obtained. The reaction is studied more closely with respect to the spectrum and reactions of this species. It is found to react with bicarbonate yielding the carbonate radical, which probably explains - at least partly - why bicarbonate and carbonate protect ozone in aqueous solutions. On exposing Ar, N_2O, and O_2 saturated solutions of ozone to γ-rays we find this species to be the chain carrier in the destruction of ozone.

3.3 Formation of ozone in the reaction between the ozonide radical ion, O_3^-, and the carbonate radical ion, CO_3^-, in aqueous alkaline solutions[§]

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

Ozone forms in aqueous alkaline solutions by a reaction between the O_3^- and CO_3^- radical ions. This reaction has been demonstrated under conditions favorable for the generation of suitable concentrations of these ions by a high-pressure pulse radiolysis technique. The reaction is: $O_3^- + CO_3^- \rightarrow O_3 + CO_3^=$.

Its rate constant $k(O_3^- + CO_3^-)$ of $(6 \pm 2) \times 10^7\ dm^3 mol^{-1} s^{-1}$ has been determined by computer simulation of the reactions involved.

3.4 Ultraviolet spectrum and decay of the ozonide ion radical, O_3^-, in strong alkaline solution[§]

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

Pulse radiolytic experiments in strong alkaline solution (pH 13-14) on the formation and decay of the ozonide ion radical, O_3^-, are reported. The high pressure cell technique was used applying 4 MPa nitrous oxide and 0.1 MPa oxygen. The spectrum of O_3^- in UV was measured and the decay product was identified as the peroxy radical ion, O_2^-. A complete mechanism for the decay of O_3^- is based on the reactions: $O_3^- + O^- \rightarrow 2O_2^-$ and $O_2^- + O^- \xrightarrow{H_2O} O_2 + 2OH^-$. A computer simulation of the high-pressure system as well as the atmospheric pressure oxygenated system supports this mechanism and yields a rate constant, $k(O_3^- + O^-)$ of $(7.0 \pm 1.0) \times 10^8\ dm^3 mol^{-1} s^{-1}$. As a consequence of our mechanism a $k(O_2^- + O^-)$ of $(6.0 \pm 1.0) \times 10^8\ dm^3 mol^{-1} s^{-1}$ is also derived from the computations.

3.5 The ozonide ion radical, O_3^-, decay in aqueous solutions, pH 10-12

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

In the pulse radiolysis of aqueous solutions at pH 10-12 using a high-pressure cell technique, the peroxy radical O_2^- is identified as the final product from the decay of the ozonide ion radical. Similar to stronger alkaline solution (pH 13-14) the reaction

$$OH + O_3^- \rightarrow [HO_4^-] \rightarrow 2O_2^- + H^+ \qquad (1)$$

is suggested to be responsible for the decay. This reaction, however, is incomplete in explaining the full mechanism as both the kinetics at 430 nm (O_3^-) and 250 nm (O_2^-) and the computor simulations suggest a simultaneous reaction where the product could be ozone

$$OH + O_3^- \rightarrow O_3 + OH^- \qquad (2)$$

Ozone reacts rapidly with O_2^- (1.5×10^9 $dm^3mol^{-1}s^{-1}$) forming O_3^-.

A decay on top of the O_2^- absorption at 260 nm and a corresponding build-up at 430 nm indicate that this reaction takes place.

From the computations it is suggested that reaction (2) is about 1/3 of the overall reaction and that the overall rate constant is $k(OH + O_3^-) \simeq 9\times10^9$ $dm^3mol^{-1}s^{-1}$.

3.6 Reactions of one-electron transfer from the ozonide radical ion

(U. Kläning (Chemistry Department, Aarhus University), J. Holcman and K. Sehested)

The oxydation of O_3^- to ozone by carbonate radicals (J. Holcman, K. Sehested and E.J. Hart, J. Phys. Chem., May 1982) suggests that O_3^- also can react by one-electron transfer with strong one-equivalent oxidants such as BrO_2, BrO, ClO_2, and ClO. An investigation of these reactions is undertaken.

3.7 Radiolysis of bromate and chlorate solutions

(U. Kläning and N. Bjerre (Chemistry Department, Aarhus University), E. Larsen (Chemistry Department), and K. Sehested)

Pulse radiolysis experiments show no net reaction of bromate and chlorate ions with O^- (or OH) which might be due to a fast dissociation of O^- (or OH) adducts of chlorate and bromate. Mass spectroscopic measurements of oxygen isotope exchange between solute anions (chlorate and bromate) and water solvent have been performed. Experiments with solutions of 2×10^{-4} M $KClO_3^{18}$ and $KBrO_3^{18}$ in H_2O^{16} at $8 < pH < 11.3$ saturated with N_2O^{16} and irradiated with 10-60 krad (dose rate 3.3×10^5 rads/h) do not lead to a measurable exchange of O^{18} with O^{16}. This suggests that the reaction of O^- (and OH) with BrO_3^- and ClO_3^- is relatively slow ($< 10^5\ M^{-1}s^{-1}$).

3.8 Reaction between $HO_2^{\bullet}$ and chlorine in aqueous solution§

(E. Bjergbakke, S. Navaratnam and B.J. Parsons (School of Natural Sciences, North E Wales Institute, Connah's Quay Clwyd, UK), and A.J. Swallow (Paterson Laboratories, Christie Hospital and Holt Radium Institute, Manchester, UK))

Reactions in aqueous solution containing ferrous sulfate are among the best understood of radiolytic reaction mechanisms, but hitherto unsuspected reactions must be taking place when large radiation doses are applied instantaneously in the presence of added chloride. We have recently found indications that yields under these conditions might be explicable if $HO_2^{\bullet}$ radicals reduce Cl_2. This communication reports independent confirmation of this reaction, obtained in a system designed to demonstrate it.

3.9 Computer simulation 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 reaction mechanism is still insufficient to obtain acceptable computer fits to the experimental results.

3.10 Pulse radiolysis of Cl^- solutions

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

In pulse radiolysis of N_2O-saturated Cl^- solution a build-up of an absorption at 350 nm in a µsec time scale has been observed previously. The spectrum of the build-up absorption reveals features of the $ClOH^-$ and Cl_2^- species. This build-up has previously been ascribed to the protolytic reaction of $ClOH^-$ ($ClOH^- \rightleftarrows ClO^{--} + H^+$). This reaction, however, can now be excluded because neither on the rate of the build-up nor on the absorption is an effect of increasing pH observed. From pulse radiolytic experiments with high-pressure H_2 we find that Cl_2^- does not react with hydrogen at pressures of up to 150 atm, whereas $ClOH^-$ reacts with H_2 with a rate constant close to that of the OH radical. We found that H_2 suppresses the build-up at 350 nm, which indicates that $ClOH^-$ is the precursor for the absorbing species. Contrary to earlier findings we observe an increase in the rate of this build-up with Cl^- concentrations although weaker than proportional.

The yield of the Cl_3^-, which is the product of the second-order decay of the Cl_2^-, suggests that the build-up is due to the reaction $ClOH^- + Cl^- \rightarrow Cl_2^- + OH^-$ (1) in analogy with the reactions for iodide and bromide ions. Because of a relatively slow rate of reaction (1) and the complexity of the system, this reaction cannot be separated in pulse radiolytic experiments. Therefore a computer simulation has been applied, which takes all the reactions involved into account. The computer simulations are in agreement with the experimental data assuming a rate constant of reaction (1) $k = 2 \times 10^5\ dm^3 mol^{-1} s^{-1}$.

3.11 Reactions of hydroxyl radicals with hydrogen peroxide at ambient and elevated temperatures[§]

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

The reaction of hydroxyl radicals with hydrogen peroxide has been studied in the pH range 6.8 - 13.8. $k(OH + H_2O_2)$ was determined to be $(2.7\pm0.3)\times10^7\ dm^3 mol^{-1} s^{-1}$ and $k(O^- + HO_2^-)$ to be $(4.0\pm0.5)\times10^8\ dm^3 mol^{-1} s^{-1}$. The rate constants of the cross reactions $OH + HO_2^-$ and $O^- + H_2O_2$ could not be determined separately. However, an upper limit of $k(O^- + H_2O_2) = 5 \times 10^8\ dm^3 mol^{-1} s^{-1}$ was measured. Consequently, by disregarding this reaction, $k(OH + HO_2^-)$ can be determined to $(7.5\pm1.0)\times10^9\ dm^3 mol^{-1} s^{-1}$.

The reaction between OH and H_2O_2 was studied at pH 7.8 in the temperature range 14-160°C and an activation energy of 14 kJ mol^{-1} (3.4 kcal mol^{-1}) was derived from the Arrhenius plot with a rate constant of $(2.7\pm0.3)\times10^7\ dm^3 mol^{-1} s^{-1}$ at 20°C.

3.12 Reaction of hydroxyl radicals with hydrogen at elevated temperatures

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

The reaction of hydroxyl radicals with hydrogen in aqueous solutions has been studied in the temperature range 20-230°C. The rate constant of the reaction was determined either by competition kinetics using Cu^{2+} as the competitor or through measurement of the formation rate of O_2^- in aqueous solutions of oxygen and hydrogen. The rate constant at 20 and 230°C is

$(3.7 \pm 0.3) \times 10^{7}$ and $(1.0 \pm 0.2) \times 10^{9}$ $dm^{3}mol^{-1}s^{-1}$, respectively. The activation energy of the reaction is 20 kJ mol^{-1} (4.7 kcal mol^{-1}).

3.13 Activation energy of O^{-} + H and H + OH^{-}

(B. Hickel (Saclay, France) and K. Sehested)

The temperature-pressure cell technique was used to determine the activation energy of the O^{-} + H_2 and H + OH^{-} reactions. The measurements were performed in alkaline solutions with high-pressure hydrogen following the build-up of the hydrated electron. Because the electron is simultaneously decaying the experimental data are now being treated by computer to evaluate the correct rate constants.

3.14 Dissociation and dioxygen formation in hydroxide solutions of tris(2,2-bipyridyl)iron(III) and tris(1,10-phenanthroline)iron(III): Rates and Stoichiometry.

(G. Nord, B. Pedersen (Chemistry Lab. I, H.C. Ørsted Institute) and E. Bjergbakke)

The fast redox reactions of the title Fe(III) complexes in basic solutions give the Fe(II) complexes and coordinated ligand N-oxide as primary products. Further reactions by parallel paths include dissociation to give the free ligand N-oxide and catalysis by hydroxy-Fe(III) complexes leading to dioxygen. No O_2 is produced when dissociation of tris(2,2'-bipyridyl)Fe(III) is suppressed by addition of excess ligand; the dependence of the O_2 yield on the degree of dissociation of this complex can be reproduced using the rate constants for the parallel catalysed and uncatalysed decay of the first product.

3.15 Pulse radiolysis of methyl viologen in aqueous solutions. I. Reducing radicals[§]

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

Pulse radiolysis of airfree aqueous methyl viologen (MV^{2+}) solutions were carried out at various pH's. The attack of e^-_{aq} on MV^{2+} with $k(e^-_{aq} + MV^{2+}) = 7.5 \times 10^{10}$ $dm^3mol^{-1}s^{-1}$ leads to the formation of the long-lived radical cation ($\dot{M}V^+$), which possesses two absorption maxima at 392.5 nm ($\varepsilon_{392.5} = 4200$ m^2mol^{-1}), and 600 nm ($\varepsilon_{600} = 1450$ m^2mol^{-1}). The H-atoms react with MV^{2+} at pH 1 forming two species with superimposed absorption bands. By means of a computer simulation the bands are resolved in the absorptions belonging to: 1) A protonated form of the radical cation ($\dot{M}V^+H^+$) produced with a $k(H + MV^{2+}) = (3.5\pm0.2)\times10^8$ $dm^3mol^{-1}s^{-1}$, which has 2 absorption maxima: at 390 nm ($\varepsilon_{390} = 1700$ m^2mol^{-1}) and 595 nm ($\varepsilon_{595} = 760$ m^2mol^{-1}) and decays by second-order kinetics with $k = 3.5 \times 10^9$ $dm^3mol^{-1}s^{-1}$. 2) An H-adduct ($\dot{M}V^{2+}H$) on ring carbon, formed with a $k(H + MV^{2+}) = 2.5 \times 10^8$ $dm^3mol^{-1}s^{-1}$, absorbing at 310 nm ($\varepsilon_{310} = 900$ m^2mol^{-1}) and 470 nm ($\varepsilon_{470} = 630$ m^2mol^{-1}) and decays by conversion into $\dot{M}V^+H^+$ in a first-order process with a $k = 6 \times 10^3$ s^{-1}. For the equilibrium: $\dot{M}V^+H^+ \rightleftarrows \dot{M}V^+ + H^+$ a pK = 2.9±0.1 was determined. The presented data explain, at least partly, the instability of MV^{2+} used as electron acceptor in various devices for solar energy utilization.

3.16 Pulse radiolysis of methyl viologen in aqueous solutions. II. Oxydizing radicals.

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

In order to determine the reactivity and reactions of OH-radicals with MV^{2+}, pulse radiolysis studies with 2×10^{-4} mol dm^{-3} MV^{2+}, saturated with N_2O (pH = 6.3), are carried out. A conversion of e^-_{aq} into OH ($G_{OH} = 5.5$) takes place and the transient spectrum shows absorption maxima at 395, 470, and 570 nm. Following the build-up of the transient at 470 and 570 nm a rate constant for the reaction of OH with MV^{2+} is determined as:

$$k(OH + MV^{2+}) = 4 \times 10^{8}\ dm^{3}mol^{-1}s^{-1}$$

The formation and decay kinetics are studied at various pH's and dose rates. The reaction mechanism seems rather complicated, which indicates the possibility of forming various OH-adducts.

3.17 The reaction of N,N-dimethylaniline radical cation in strongly alkaline solution[§]

(J. Holcman and K. Sehested)

The radical cation of N,N-dimethylaniline (DMA) is formed in N_2O-saturated 0.1-1.0 mol dm^{-3} sodium hydroxide solution by scavenging the O^-/OH radical with CNS^- ions. The $(CNS)_2^-$ radical thus formed facilitates a one-electron oxidation. The DMA radical cations react then with OH^- ions by abstraction of a methylic proton forming the corresponding substituted methyl radical $C_6H_5N(CH_3)_2^{\dot{+}} + OH^- \rightarrow C_6H_5N(CH_3)\dot{C}H_2 + H_2O$ with a rate constant $k = 1.5 \times 10^{5}\ dm^{3}mol^{-1}s^{-1}$.

3.18 Contract work for Studsvik Energiteknik AB

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

The work consists of program development and computer simulation of a) Radiation chemistry in connection with radioactive waste disposal, and b) Reactor chemistry in a LOCA (Loss of Coolant Accident). The results were presented at an international conference by H. Christensen and published in Studsvik Reports.

3.19 References

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

4.1 Radiochromic dye film dose meters

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

Thin-film plastic dose meters are produced and their properties are investigated. Part of this work was carried out under a research contract with IAEA (2051/RB), which is now terminated. Under a new contract (2883/RB) the dose meters' electron beam characteristics are investigated. The production of the dose meter films on an industrial scale is now being attempted in cooperation with a private company.

4.2 Calorimetry

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

In connection with the above-mentioned electron beam work, a proper determination of the electron beam parameters of our accelerators is initiated. A semi-adiabatic calorimeter designed by B. Radak for use on the 400-keV ICT accelerator was modified and its ability to calibrate film dose meters is now investigated. Work is also in progress for testing the water calorimeter, which for several years has been in use at the 10-MeV linac. This work is organised in cooperation with the IAEA.

4.3 International dose intercomparison

(A. Miller)

IAEA is organizing a programme with the aim of establishing an international dose assurance service for industrial gamma irradiation facilities. A recommendation was made for initiating this service, and for expanding the programme to cover electron beam facilities as well. Our calorimetry work is part of this programme.

4.4 Lyoluminescence dosimetry

(A. Miller)

Several materials emit light upon dissolution after irradiation. This property in amino acids and sacharids has been utilized for dosimetry in the range of 10 Gy - 10 kGy (1-1000 krad). Recently a complete lyoluminescence measurement apparatus was acquired from K. Puite, ITAL, Wageningen, giving us a dose meter in a range which we have not previously been able to cover. Lyoluminescence of glutamine has been used in the IAEA's intercomparison work and the intention is to carry on this work.

4.5 Calculation of the energy dependence of dose meter response to ionizing photons[§]

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

A programme in BASIC for a desk-top calculator is designed to facilitate calculations of energy dependence correction factors of dose meter readings of absorbed dose according to cavity theories. Burlin's general cavity theory is applied in the present calculations, and certain limitations of the theory are considered.

Examples of the use of the programme are given for ^{60}Co gamma-ray irradiation of a LiF dose meter held in aluminum and for evaluating the influence of changes in broad gamma-ray spectra on the response of several dose meters.

4.6 Commercially oriented activities

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

Test irradiations as well as small-scale industrial irradiation have been carried out for several firms. In one case we have irradiated materials in large quantities for a single firm.

Consulting activities and measurements of dose and dose distributions have been carried out in several cases.

Because of the increased interest for food irradiation - also in Denmark - we have continued the measurements of the very limited amounts of radioactivity which might be induced by 10-MeV accelerator irradiation. This work is carried out in co-operation with the Safety Department (Per Hedemann Jensen).

4.7 Radiation physics

(J.W. Hansen, Kjeld Olsen (Dept. of Radiophysics, Københavns Amts Sygehus, Herlev), and R. Katz (University of Nebraska-Lincoln, USA))

Work has been concentrated on modifications of the model of track structure theory for predicting dose-response characteristics of high-LET particles. Theoretical data have been tested against experimental results from irradiation of the dye film dose meter with a wide range of particle LET (2-7000 $MeVcm^2/g$). Computer programmes for B6700 have been in progress with three different solutions to the range-energy relation of the delta rays generated by the ion in the target material. As a first approach a simple linear range-energy formulation has been chosen leading to an analytic solution to a dose integral, but the formalism underestimates the range of the delta-rays at low energies resulting in RBE-values (Relative Biological Effectiveness) that are too high compared with values obtained from experiments. An exponential formulation has been made to fit range-energy values as calculated in a continuous slowing down approximation (c.s.d.a.) from recently published stopping power data (Paretzke) for low-energy electrons in water. This fit is more realistic, and the final results of RBE are in better agreement with experiments. A third formulation includes the published stopping power data as well, but used as an array of c.s.d.a. range data in the computer. The energies corresponding to a certain range are calculated by means of a Lagrange interpolation formalism. At the moment these results are not satisfying probably because they cut off at too high an electron energy (10 eV) thereby omitting exitation energies. We have compared our calculated dose profile based on the exponential range-energy fit with an experimentally obtained profile (Varma et al.) of a fast bromine ion in water vapour and found good agreement.

The experimental equipment has been modified in order to get more accurate results especially regarding the heavier ions. New energy-defining slits assure homogeneity in the charge state of the ions to the target. A strong magnetic field around the entrance to the Faraday cup and a high potential ring between the target and Faraday cup traps the secondary electrons formed.

A decision to gain knowledge about the alanine dose meter in the context of track physics has been made, and we have started to make equipment for these experiments. The first pills of compressed alanine and cellulose have been made in a size appropriate for the Risø ESR spectrometer, but the pills were easily cracked because of too small a diameter. It will be necessary to use pills of a larger diameter and to change the set-up in the spectrometer.

4.8 Detection of individual tracks of heavy ions in the thin-film detector

(J.W. Hansen and R. Katz (University of Nebraska-Lincoln, USA))

Calculations on the dose profile around the track of a densely ionizing heavy particle in the dye film show possibilities of determining tracks of individual particles visually in a microscope. These tracks differ from those in nuclear emulsions by the greater difference in size of the molecule, the sensitive element in the dye film, compared with the silver bromide grain in the emulsion. This will thus give an image of the actual dose distribution at a much higher resolution.

Samples of dye film have been irradiated at the heavy ion accelerator at Gesellschaft für Schwerionen Forschung (GSI) in Darmstadt.

4.9 References

Johnny W. Hansen and Mads Wille, A Fast Non-Intercepting Linac Electron Beam Position and Current Monitor. Submitted: Nucl. Instrum. & Meth.

Johnny W. Hansen and Kjeld J. Olsen, Experimental and Predicted Effectiveness of High-LET Radiation to the Radiochromic Dye Film Dose Meter. Submitted: Radiat. Phys. Chem.

Arne Miller, Calculation of Energy Dependence of Dose Meters. Submitted: J. Appl. Rad. & Isotopes.

A. Miller and W. Batsberg Pedersen, Bestråling af plast (Irradiation of Plastic). Submitted: Project.

5. RADIATION BACTERIOLOGY RESEARCH

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

5.1 Sensitivity of exponentially growing populations of Escherichia coli to photo-induced psoralen-DNA interstrand crosslinks

(N.B. Grover and A. Margalit (Hebrew University-Hadassah Medical School, Jerusalem, Israel), A. Zaritsky (Ben-Gurion University, Beer-Sheva, Israel), E. Ben-Hur (Nuclear Research Centre Negev, Beer-Sheva, Israel), and M.T. Hansen)

Experimental survival curves for Escherichia coli K 12 (CR 34) were determined after exposure to 4,5', 8-trimethylpsoralen and near ultraviolet light. The lethal action was shown to arise exclusively from interstrand crosslinks, cell vulnerability increasing markedly with the doubling time of the culture. To account for these results, two contrasting models are considered. The first assumes that a cell survives as long as at least one copy of its genome remains undamaged; a variant of this permits repair by DNA strand exchange. The second model allows for a limited period of time during which DNA repair can take place. A crosslink in a stretch of DNA due to be replicated within this interval constitutes a fatal lesion. Theoretical survival curves are computed for bacterial populations with defined age distributions and chromosome configurations. While the first model completely fails to provide a satisfactory description of the experimental results, the second does predict the presence of a shoulder in the survival curves and, in one of its forms, it seems to agree rather well with the measured data over a wide range of crosslink concentrations and doubling times.

5.2 Sensitivity of Escherichia coli acrA mutants to psoralen plus near ultraviolet radiation

(M.T. Hansen)

The sensitivity to psoralen plus near ultraviolet light (PUVA) was compared in a pair of E. coli strains isogenic except for the acrA locus. AcrA mutants were forty times more sensitive to the lethal effect of PUVA than the wild type. Free λ phage exposed to PUVA survived as well when plated on acrA mutants as on the wild type. In contrast, λ CI857 ind$^-$ was very sensitive to PUVA when carried by lysogenic acrA strains. The hypersensitivity of bacterial and λ DNA, when inside acrA cells, was paralleled by an increased photobinding of radio-labelled psoralens in the mutant. Binding was increased specifically to DNA rather than to nucleic acids in general. The acrA-determined difference in psoralen binding ability persisted after permeabilizing treatment of the cells. The data suggest that the acrA mutation causes an alteration in the environment of the cellular DNA so as to allow increased intercalation and photobinding of psoralens.

5.3 Rescue of mitomycin-C or psoralen inactivated *Micrococcus radiodurans* by additional exposure to radiation or alkylating agents

(M.T. Hansen)

The processing of damaged DNA was altered in a mitomycin-C sensitive mutant (mtcA) of *Micrococcus radiodurans*. The mutant, which retains resistance to UV radiation, did not show the characteristic wild type excessive DNA degradation and cell death after sublethal doses of either UV light or mitomycin-C followed by incubation with chloramphenicol. After exposure to ionizing radiation, which introduces DNA strand breaks by direct, nonenzymatic action chloramphenicol did, however, promote loss of viability equally in wild type and mutant strain. The data suggest constitutive synthesis of an enzyme system responsible for wild type proficiency in the repair of mitomycin-C induced damage.

An alternative system able to repair damage caused by mitomycin-C was demonstrated in the mtcA background. In the mutant, additional damage inflicted upon the cellular DNA effected a massive rescue of cells previously inactivated by mitomycin-C. Thus, a dose of 200 krad of ionizing radiation increased the survival by a factor of a thousand from 10^{-4} to 10^{-1}. Similarly, efficient rescue was provoked by UV radiation or by simple alkylating agents. Cells treated with psoralen plus near ultraviolet radiation could be rescued only when inactivation was due primarily to psoralen-DNA interstrand crosslinks rather than to monoadducts. Rescue of inactivated cells was prevented in the presence of chloramphenicol. These results can most readily be interpreted in terms of an alternative repair system able to overcome DNA interstrand crosslinks produced by mitomycin-C or psoralen plus near ultraviolet light, but induced only by the more abundant number of damages produced by radiation or simple alkylating agents.

5.4 W-reactivation in *Acinetobacter calcoaceticus*

(D. Berenstein)

Weigle(W)-reactivation was demonstrated in *A. calcoaceticus* for the UV-irradiated lysogenic phage P78. The reactivation factor (survival of irradiated phage on irradiated bacteria/survival on unirradiated bacteria) reached a maximum value of 20. This was obtained at UV-doses giving phage and host survivals of about 5×10^{-6} and 1×10^{-1}, respectively. Intracellular development of W-reactivated P78 was followed by one-step growth experiments. Conditions which allowed maximal W-reactivation also extended the period of phage production and yielded a somewhat reduced burst size.

W-reactivation in E. coli is a part of an error-prone repair process, which also causes induction of prophages and inhibition of cell division, with resulting filamentons growth. Filament formation as a response to UV-irradiation has also been observed in *A. calcoaceticus*. In order to study the kinetics of prophage induction after UV-irradiation, a lysogenic strain of A. calcoaceticus has been isolated.

5.5 Genetic mapping of *Acinetobacter calcoaceticus*

(D. Berenstein)

The genetics of *A. calcoaceticus* is almost unknown. A transducing phage and conjugation system have been described a few years ago, but no linkage between different markers could be demonstrated. A. calcoaceticus strains containing plasmids able to mobilize bacterial chromosome have been obtained from Dr. A. Vivian, Thames Polytechnic (London). The plasmids have been introduced into our own A. calcoaceticus strains that are now being used for: 1) genetic mapping of A. calcoaceticus, especially for genetics of radiation resistance and 2) influence of plasmids on W-reactivation and on radiation resistance.

5.6 References

M. Trier Hansen, Sensitivity of Escherichia Coli acrA Mutants to Psoralen Plus Near Ultraviolet Radiation. Submitted: Mutation Research.

M. Trier Hansen, Rescue of Mitomycin-C or Psoralen Inactivated Micrococcus Radiodurans by Additional Exposure to Radiation or Alkylating Agents. Submitted: J. Bacteriol.

6. EDUCATIONAL ACTIVITIES AND PUBLICATIONS

6.1 Lectures

D. Berenstein, Strålesterilisation af Medicinsk Éngangsudstyr (Radiation Sterilization of Medical Disposable Equipment) for studerende ved Danmarks Sygeplejeskole. Risø, 8. April.

H. Christensen and E. Bjergbakke, Radiation Chemistry in Connection with Radioactive Waste Disposal. Workshop on Evaluation of Systems Variable in Long Term Performance of Nuclear Waste Solid. Gainesville, USA, 3-5. February.

J.W. Hansen, Fysisk-biologisk Model for Tunge Ioners Biologiske Effekt og Anvendelse i Radioterapien (Physical-biological Model Describing the Biological Effectiveness and Applications in Therapy of Heavy Ions). Københavns Amts Sygehus, Herlev, 12. & 19. February.

J.W. Hansen, Eksperimentelle og Teoretiske Undersøgelser af en Tynd-film Enkelt-hit Detektor Beskrevet ved Teorien for Sporstruktur for Tunge Ioner (Experimental and Predicted Effectiveness of a Radiochromic Dye Film Dose Meter to High-LET Radiation). Københavns Amts Sygehus, Herlev, 26. February.

J.W. Hansen and K. Olsen, Prediction of High-LET Dose Response Characteristics from Detector Parameters of Low-LET Radiation (Poster). 7. Meeting in Nordic Society for Radiation Research and Radiation Technology, Gol, Norway, 8-11. March.

R. Katz, Biological Aspects of Low and High LET, Low Dose, Irradiation. Risø, 25. August.

R. Katz, Radiobiological Aspects of Heavy Ion Beam Irradiation in Therapy. Københavns Amts Sygehus, Herlev, 27. August.

A. Miller, Dosimetry. 7. Meeting in Nordic Society for Radiation Research and Radiation Technology, Gol, Norway, 8-11. March.

A. Miller, Advances in Dosimetry. Raychem Ltd., Durcan Swindon, Wiltshire, England, 19. June.

A. Miller, Simplified Calculation of Cavity Theory Corrections. IAEA-CN-40/12P. International Conference on Industrial Application of Radioisotopes and Radiation Technology. Grenoble, France, 28. September - 2. October.

A. Miller, Advances in High-Dose Dosimetry. Nuclear Research Institute, Řež, Czechoslovakia, 16. November.

B. Pedersen, G. Nord and E. Bjergbakke, Dissociation and Dioxygen Formation in Hydroxyl Ion Reduction of Tris(2,2-bipyridyl)- and Tris(1,10-phenanthroline) Iron (III). Rates and Stoichiometry. H.C. Ørsted Institute, Copenhagen, 30. November.

7. Danish-Polish Symposium on Radiation Chemistry, Risø 7-9, September:

E. Bjergbakke, Reactions Between HO_2 and Chlorine in Aqueous Solution.

H. Christensen, Reactions of Hydroxyl Radicals with Hydrogen Peroxide at Ambient and Elevated Temperature.

J. Fenger, Intensity-stabilized Pulsed Analyzing Lamp for Ultraviolet Transient Spectrometry.

J.W. Hansen and K.J. Olsen, High-LET Dose Response Characteristics Described by Track Structure Theory of Heavy Charged Particles.

J. Holcman, Decay of the Ozonide Ion Radical in Alkaline Solutions.

E. Jaworska, Influence of Radiation Crosslinking on Stresses in Deformated Polyethylene.

H. Józwiak, Radiation Curable Coating Compositions.

Z. Luczyński, Ion Reactions in $C_2H_5ONO_2$ in Gas Phase.

J. Michalik, The ESR Studies of Allyl Radical Reactions in Complex Matrices at 77 K and 4 K.

A. Miller, Simplified Cavity Theory Calculations Using Burlin's Cavity Theory.

O. Mogensen, J. Rud Andersen and N.J. Pedersen, Competitive Hydrated Positron Reactions with Halides.

O.J. Nielsen, H-atom Yields in Gas Phase Pulse Radiolysis of H_2.

P. Panta, The Radiation Effects in the Silicon Power Devices.

P. Panta, An Improved Calorimetric Dosimetry for Radiation Processing and Pulse Radiolysis on Linac.

E. Ratajczak and P. Pagsberg, Heats of Formation of Free Radicals Determined by Studies of Gas Phase Equilibria in a Very Low Pressure Discharge Flow Reactor.

W. Batsberg Pedersen, The Contribution of Chain-entanglements in Radiation-crosslinked polybutadiene.

K. Sehested, Radical Reactions with Ozone in Aqueous Solutions.

Z.P. Zagorski, Electron Trapped in Low Water Hydrates - Structural Aspects.

Z.P. Zagorski, Examples of Computation of up to 50 Competing Reactions After Pulse of Electrons Obtained With Cyber 72 Machine.

Z.P. Zagorski, Minicomputer for Accelerator and Pulse Radiolysis Application.

6.2 Publications

Accelerator Department Annual Progress Report (1981). 1. January - 31. December 1980. Risø-M-2287.

E. Bjergbakke, S. Navaratnam, B.J. Parsons and A.J. Swallow (1981), Reaction Between HO_2 and Chlorine in Aqueous Solution. J. Am. Chem. Soc. 103 (19), 5926-8.

E. Bjergbakke (1981), Computer Simulations Control. Intern arbejdsrapport, samarbejde med Studsvik Energiteknik AB, Sverige.

H. Christensen and E. Bjergbakke (1981), Radiolys Vid Avställning Av 01. Studsvik Technical Report NW-81/29.

H. Christensen and E. Bjergbakke (1981), Radiolys Vid Avställning Av 01. Studsvik Technical Report NW-81/54.

H. Christensen and E. Bjergbakke (1981), Radiolys Vid Avställning Av 01. Litteratursökning. Studsvik Technical Report NW-81/72.

H. Christensen and K. Sehested (1981), Pulse Radiolysis at High Temperatures and High Pressures. II. Radiat. Phys. Chem. 18, Nos. 3-4, 723-731.

J. Fenger (1981), Intensity Stabilized Pulsed Analyzing Lamp for Ultraviolet Transient Spectrometry. Rev. Sci. Instrum. 52 (12) 1847-1851.

N.B. Grover, A. Zaritsky, E. Ben-Hur, A. Margalit, and M.T. Hansen (1981), Sensitivity of Exponentially Growing Populations of Escherichia coli to Photoinduced Psoralen-DNA Interstrand Crosslinks. Biophys. J. 33, 93-106.

J.W. Hansen and K.J. Olsen (1981), High-LET Dose-Response Characteristics Described by Track Structure Theory of Heavy Charged Particles. Risø-M-2308.

J.W. Hansen (1981), Fysisk-biologisk Model for Tunge Ioners Biologiske Effekt og Anvendelse i Radioterapien. Risø-M-2315.

J.W. Hansen, M. Jensen and R. Katz (1981), The Radiochromic Dye Film Dose Meter as a Test of Particle Track Theory. Proceedings of the 7th Symposium on Microdosimetry, 8-12 September 1980, Oxford, Vol. II, 821. Harwood Academic Publishers Ltd.

U.Kläning, K. Sehested and Th. Wolff (1981), Laser Flash Photolysis and Pulse Radiolysis of Iodate and Periodate in Aqueous Solution. J. Chem. Soc. Faraday Trans I 77, 1707-1718.

A. Miller and W.L. McLaughlin (1981), Evaluation of Radiochromic Dye Films and Other Plastic Dose Meters under Radiation Processing Conditions. In "High-Dose Measurements in Industrial Radiation Processing", IAEA Technical Reports Series No. 205, IAEA, Vienna.

A. Miller (1981), Investigation of the Radiochromic Dye Film Dose Meter under Process Conditions, Including Stability, Precision, Accuracy, the Influence of Dose Rate and the Influence of the Environment. Final Report (August 1977 - July 1981). IAEA Research Contract 2051/RB, IAEA, Vienna.

A. Miller and W. Batsberg Pedersen (1981), Dose Distribution in Electron Irradiated Plastic Tubing. Radiat. Phys. Chem. 18, Nos. 5-6, 967-973.

6.3 Test-irradiations

Test-irradiations were carried out for:

Fa. Alfred Benzon, København
DanCake, Give
Danmarks tekniske Højskole, Lyngby
Dæhnfelt, Middelfart
Fibiger-Laboratoriet, København
Harald V. Lassen, Valby
Marselisborg Hospital, Århus
Meda A/S, Herlev
Mölnlycke A/S, Espergærde
A/S Nunc, Kamstrup
Proteinlaboratoriet, Københavns Universitet
Sankt Hans Hospital, Roskilde
V. Schelbeck, Agedrup
Statens Seruminstitut, København.

6.4 Visiting scientists

B. Berlin, Studsvik Energiteknik AB, Nyköping, Sweden.
A. Brynjolfsson, US Army Natick Laboratories, Natick, MA, USA.
W.G. Burns, Atomic Energy Research Establishment, Harwell, Oxfordshire, England.
L. Bøgh-Sørensen, Den kgl. Veterinær- & Landbohøjskole, København.
H. Böök, OY Fiskars AB, Ekenäs, Finland.
N. Getoff, Institut für Strahlenchemie, Vienna, Austria.
H. Grabner, Voest-Alpine, Linz, Austria.
K. Göksay, Nuclear Research Institute, Ankara, Turkey.
F. Hansen, Santax, Rødovre
E.J. Hart, Port Angeles, WA, USA.
B. Hickel, Saclay, Gif sur Yvette, France.
W. Karmann, Beiersdorf, Hamburg, Germany.
U. Kläning, Kemisk Institut, Aarhus Universitet, Aarhus.
R. Katz, University of Nebraska, Lincoln, NE, USA.
Lé Xúan Tú, National Centre for Scientific Research of Vietnam, Hanoi, Vietnam.
J. McKeown, Atomic Energy of Canada, Chalk River, Ont., Canada.
W.L. McLaughlin, National Bureau of Standards, Washington, DC, USA.
T. Olejnik, Johnson & Johnson, East Windsor, NY, USA.
B.J. Parsons, North E Wales Institute, Connahs Quay, N. Wales, England.
C.E. von Schantz, Nokia Engineering, Helsinki, Finland.
S. Solar, Institut für Strahlenchemie, Vienna, Austria.
F. Spengler, Voest-Alpine, Linz, Austria.
Zhung Zu-Hua, Shanghai University of Sciences and Technology, Shanghai, China.

7. IRRADIATION FACILITIES AT THE ACCELERATOR DEPARTMENT

Electron Accelerators

1. Linear Electron Accelerator, Haimson Research Corp. Model HRC-712

Specifications:

Electron energy	10 MeV
Average electron current	1 mA
Peak electron current at 10 MeV	1100 mA
Pulse length, normal mode	1 - 4 µs
Pulse length, short pulse mode	10 - 1000 ns
Pulse repetition rates	single pulses and 12.5, 25, 37.5, 50, 100, 150 and 200 pps
Energy spread	78% of the beam current within a spread of ± 2.5%
Pulse-to-pulse dose variation:	
a) within a pulse train, less than	1.8%
b) for single pulses separated at 10 min. intervals, less than	3%
Electron pulse flatness over a 2 µs interval, better than	± 1%

Accelerator room beam facilities:

1. A bent beam with scan width of 40 cm in connection with a conveyor system provides a process irradiation capacity of 700 Mrad kg/hour.
2. Two horizontal beam ports, full average beam peak power, for electron and X-ray irradiation.
3. One horizontal beam port, reduced average beam power (12.5 pps) in connection with a ± 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 (electron mode)	20 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 conveyors to permit pilot-plant irradiation.

^{60}Co-Facilities

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

Designed for very homogeneous irradiation of samples with a maximum length of 1,000 mm and diameters of maximum 180, 100, or 60 mm. The corresponding maximum dose rates (8,300 Ci, 1. January 1982) are 5.0×10^5 rads/h, 1.4×10^6 rads/h, and 3.3×10^6 rads/h, respectively.

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

Designed for laboratory use and fitted with a 123 mm$^{\varnothing}$ × 150 mm irradiation chamber. The dose rate in the center of the chamber (5,000 Ci, 1. January 1982) is 4.3×10^5 rads/h. The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

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

Designed for laboratory use and fitted with a 120 mm$^{\varnothing}$ × 200 mm irradiation chamber. The dose rate in the center of the chamber (3,100 Ci, 1. January 1982) is 3.1×10^5 rads/h.

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
Jerzy Holcman
Bent Lynggård
Arne Miller

Technical Staff

Svend Bøjlund Andersen (until 18. April)
Margit Elm Andersen
Karen Boysen
Hanne Corfitzen
Ina Hansen
Jørgen Erik Hansen (from 1. September)
Inge Høegh
Torben Johansen
Erik Engholm Larsen
Fritz Larsen
Inge Merete Larsen
Kirsten Bjerring Larsen (until 31. January) Apprentice
Jesper Ljungquist (from 6. July-31. December) Apprentice
Laurits Nielsen
Gert Hagen Olsen
Kresten Pejtersen
Michael Brandt Svendsen (until 31. December)
Mads Wille

Consultants

Dr. E.A. Christensen, Chief Physician, Control Department,
Statens Seruminstitut, Copenhagen.

Dr. E.J. Hart, Port Angeles, WA., U.S.A.

W.L. McLaughlin, Physicist, Center for Radiation Research,
National Bureau of Standards, Washington, D.C., U.S.A.

Risø National Laboratory **Risø - M - 2348**

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Title and author(s)

Accelerator Department - Annual Progress Report for the period 1. January - 31. December 1981.

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Date July 1982

Department or group

Accelerator Dept.

Group's own registration number(s)

39 pages + tables + illustrations

Abstract

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

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