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Abstract

A description is given of work in the fields of irradiation technology, chemical dosimetry, radiation chemistry, physical dosimetry and radiation bacteriology research, as well as of the operation of various irradiation facilities. Appendices include specifications of the irradiation facilities.

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GENERAL INFORMATION

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).
- Customer irradiation services for laboratories within and outside Risø, for hospitals, and for industry.
- Irradiation technology studies, including the upgrading of present facilities, development of new irradiation equipment, and improvement of equipment and methods for customer irradiation services.
- Design and construction of equipment for radiation experiments.
- Radiation chemistry research in relation to chemical dosimetry and pulse radiolysis of aqueous solutions connected with fundamental problems in chemistry. This research is carried out in close collaboration with the Risø Chemistry Department and with research groups in other countries.
- Radiation physics research in relation to systems used in dose calibration and dose distribution calculations and measurements.
- Radiation bacteriological research mainly in relation to radiation sterilization problems and radiation-resistant microorganisms, and also to increase basic knowledge of the radiation resistance mechanism.
- Production and supply of bacteriological standard preparations for control of irradiation sterilization plants.
- International collaboration on the subjects mentioned above, including participation in international meetings and working groups. Bilateral collaboration arrangements are maintained with a number of scientific laboratories in Europe and in the United States.

REPORT ON THE ACTIVITIES

1. Operation and Maintenance of Irradiation Facilities[x)]

a. HRC Electron Linear Accelerator

During 1977 the accelerator was in routine operation. Except for a few shut-down periods mainly due to minor repairs, renewing of exterior installations, etc., the facility capacity came up to the expected parameters.

The weekly schedule for the accelerator is half a day for service irradiation, half a day for maintenance, and four days for experimental irradiations (mainly pulse radiolysis).

The accelerator was shut down for two weeks for installations of:

Microwave Transmitter: After 22oo hours in operation (warranty 1ooo hours - average lifetime about 5ooo hours) the high power klystron failed due to a leak in the integrated vacuum system and was replaced. At the ITT factory an inspection stated that it was not repairable. A new klystron will be delivered in January 1978.

On several occasions difficulties arose with the RF-driver generator resulting in lack of driving power to the klystron. A new sub-assembly for the driver (low power stage) was purchased in order to prevent shut-down problems in the future.

After 2ooo hours in operation (average lifetime) the tubes in the power stage of the RF-driver generator were replaced; this repair was done at the factory in USA. In the meantime a spare stage was used.

An autotransformer in the transmitter power supply broke down and was replaced by the one previously used in the old accelerator installation.

Injector System: The high voltage (225 kV) electron gun is regulated by light signals transmitted by glass fiber light links. Problems arose twice due to decreased transmission in the glass fibres (radiation induced coloration of the fibres). The problem was temporarily solved by increasing the intensity of the light signal.

Vacuum System: The beam shutter, placed in the beam centerline to shut off the target room from the accelerator room, was repaired after two years in operation due to a leak in the bellows. The original bellows was designed to take 10^4 activations; the new one is designed to take ten times as many

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[x)] Technical specifications of the facilities are listed in Appendix 4.

activations.

The fast closing safety vacuum-valve, situated in the vacuum system next to the output flange of the accelerator waveguide, malfunctioned due to radiation damage of the plastic gear wheels. The factory replaced the plastic wheels with metallic wheels.

Beam Conveyor: The 18 years old conveyor motor and electronics were replaced by new units. The new system has an increased velocity span and a better regulation. At a six hours run the velocity variations were within $\pm$ o.4%.

Water Cooling System: The cooling system for the accelerator was renewed and modified. Corrosion and wear of some of the components and insufficient water quality were the main reasons.

The 18 years old cooling tower in the tertiary system was replaced as it was corroded beyond repair. The heat capacity of the new cooling tower is 240000 kcal/h.

In order to stop the corrosion in the primary and secondary cooling loops a double bed deionizer was installed; the systems were designed for a water conductivity of 1 μ Siemens cm.

In the old heat exchanger between the tertiary and secondary system the water was exposed to the atmosphere. In order to get the full advantage of the deionizer this heat exchanger was replaced by a new closed system.

The circulation pump in the primary cooling loop did never operate satisfactorily and was replaced by another type.

b. Febetron, Field Emission Accelerator

The field emission accelerator was used for pulse radiolysis study of liquids and gases, dose distribution in the gas cell was analysed, and Raman spectroscopy experiments have been carried out.

c. ICT, Low-Energy Accelerator

The low-energy accelerator was used for dose distribution studies. The cooling water system was altered in connection with the changes in the linear accelerator cooling system. Operation was troublefree; utilization was low.

d. 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.

By medio 1977 renewing and modifications of the ^{60}Co-facility was terminated; the initial planning and repair began ultimo 1976.

After 16 years in operation some of the mechanical parts in the transmission system were renewed due to wear; the electronics for the motor drive was replaced by new solid state equipment. The modifications improved the specifications. The velocity (dose) can now be varied within a ratio of 1:100 and long time stability is better than 0.5%.

The equipment for predetermination of dose was renewed so that a more accurate dose can be given.

e. 5,000 Ci ^{60}Co-Facility

The 5,000 Ci ^{60}Co-cell, presently located in the Control Department of "Statens Seruminstitut", Copenhagen, was used for bacteriological research.

f. 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.

2. Physical Dosimetry and Technological Application of Radiation

Efforts were concentrated on dye film dosimetry, including the making of dye films, on optical techniques (holography and interferometry), computer calculation of electron interactions and on radiation technology. Collaboration in this field is maintained with W.L. McLaughlin, National Bureau of Standards, USA.

A study of the stability and dose-rate dependence of the dye films produced in the department is carried out under a contract with IAEA (2051/RB), and we take part in a preliminary international intercomparison of dosimeters for the megarad range organized by the IAEA.

Dosimetry service, including calibrations and dose distribution measurements, was carried out mainly using our own dye film along with commercial available dye films.

The gas cell used for gasphase pulsed radiolysis on the Febetron was investigated in order to increase the absorbed energy in the gas. The improvements proposed did only show a small enhancement of the absorbed dose. The dose distributions were measured with dye film dosimeters.

The dye films were used in a study of the dose distribution in wire insulation irradiated with low energy electrons.

The work with holography and interferometry was continued with investigation of the possibilities of measuring absorbed microwave power and transient reaction heats.

Investigations based on computer calculations of the interaction of electrons with matter were performed. A computer program based on a modified Landau distribution function shows the transmission number and energy spectrum of transmitted electrons through materials in the energy range of o.l - lo MeV.

A fast transient conductivity measuring equipment is being constructed for the pulsed radiolysis experiments. With a cell voltage of loo volt dc the amplifier operates in a feed back loop automatically compensating for the background conductivity, thus performing high sensitivity. To avoid overloading the amplifier is clamped during the electron pulse. The cell configuration is arranged in a coaxial geometry matching the transmission line to the amplifier and providing a proper shield against electrical disturbancies.

The investigations on producing amorphous silicon from quarts were brought to an end, as further experiments did not show any desired reaction even at a dose of loo Mrad. The experiments were carried out in collaboration with "Laboratoriet for Elektriske Halvledere", Technical University of Denmark.

The contract with potential and current industrial users of ionizing radiation was increased, partially through our participation in exhibitions and travels.

3. Chemical Dosimetry and Radiation Chemistry

The work on radical cations of methylated benzenes in aqueous solution was concluded with two papers. The first describes the formation of radical cations from the corresponding OH-adducts in an acid catalyzed process. The spectra and rate constants are measured. Some of the rate constants are measured as a function of ionic strength to prove the unit positive charge of the species. The second paper describes the reactions of the radical cations and the corresponding rate constants in acid, neutral and alkaline solution. These rate constants can all be correlated with the ionization potential of the parent compound.

The program on ethyl-, isopropyl- and tert-butylbenzene showed that the radical cation of ethyl- and isopropylbenzene is very unstable and can only be observed in very strong acid (8 M). The proton loss-reaction from the α-position is faster by a factor of ~3 from $-CH<-CH_2CH_3<CH(CH_3)_2$. The results seem to indicate a proton loss also from the β-position in tert-butylbenzene, but with a much lower rate constant.

The pulse radiolysis of N,N-dimethylaniline demonstrated an important dissociation reaction of OH-adducts, and several other compounds were studied with respect to this reaction. It was found that the rate constants for such reactions (including the uncatalyzed water elimination reactions) can be correlated with the ionization potential of the parent compounds. An analogical correlation for the radical cations reacting with OH^- was demonstrated, and those two correlations can be used for predicting either the rate of dissociation (water elimination) or the ionization potential. The last case was shown for 1,3,5-trimethoxybenzene where the two correlations within experimental error gave the same ionization potential (8.o5 eV).

In connection with the investigations of the radiolysis of simple RCN compounds of relevance to prebiotic chemistry done by Professor I. Draganić and Dr. Z. Draganić (Boris Kidrič Institute of Nuclear Sciences - Vinča, Beograd), the pulse radiolysis of cyanamide and its dimer was taken up during their stay at Risø. The radical anion absorbing in far UV and the H-adduct were detected. The hydroxyl radical adds preferentially to the cyano group, but an estimated part of ~1o% abstracts an H-atom from the amino group. Both radicals either rearrange or hydrolyze to a third radical. This radical has an absorption band at 325 nm. The optical density of this absorption band depends strongly on the dose-rate and solute concentration. This is quantitatively accounted for by assuming that the OH radicals react fast ($\sim 5 \times 10^9\ M^{-1}s^{-1}$) with the solute radical.

The results from the dimer are not yet conclusive, but also in this case a hydrolysis reaction was observed.

The pulse radiolysis study of periodate aqueous solution was made in connection with the flash photolysis of these solutions performed at Århus University. A combination of the two methods turned out to be very fruitful in the elucidation of the reaction mechanisms in the system. The I^{VII} is oxidized by OH to I^{VIII} which has an absorption between 51o-55o nm depending on the initial periodate concentration and pH. By the decay kinetics it was found that this absorption is due to several radical species or dimer species. The reduced radical I^{VI} absorbs at 360 nm with a much higher extinction coefficient (about 4000 $M^{-1}cm^{-1}$), and reacts in neutral solution with the solute by disproportionation to I^{V} and I^{VIII}. Under other experimental conditions the radical dissociates into O^{-}(OH) and I^{V}. Several rate constants of the formation and decay of the different species were measured.

A project on measuring rate constants, one-electron redox potentials and activation energies for several reactions at high temperature and pressures, was started as a joint project with AB Atomenergi, Studsvik, Sweden. The spectrophotometric temp-pressure cell was attempted to stand 350°C and 150 atm pressure. Leaks developed under these extreme conditions; however, some preliminary results on the activation energy of $e^{-}_{aq} + e^{-}_{aq}$, e^{-}_{aq} + OH, OH + Cu^{++}, etc., were obtained.

The computer program for simulation of chemical kinetics was further developed in collaboration with O. Lang Rasmussen, Computer Department. A total mass balance equation is now incorporated, and thus the quality of the integration can be read directly.

The program was used intensively in 1977. The Chemistry Department developed a Cande-version for their use. Hilbert Christensen, Studsvik, calculated the radiation chemistry of the subsoil water surrounding radioactive waste, this problem required simulation of reaction periods of millions of seconds.

Z. and I. Draganić calculated selected reactions in prebiotic chemistry. Z. Zagorski (Institute of Nuclear Research, Warsaw) calculated the radiation chemistry of oxygen saturated, strong alkaline water. In collaboration with E.J. Hart we developed and tested a total reaction mechanism of water radiolysis in the whole pH-range.

The collaboration with Martin Fielden, Royal Cancer Hospital, England, on radiolytic oxygen consumption was maintained.

4. Radiation Bacteriology Research

Bacteriological research concerns the development 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.

a. Bacteriological Research Projects

Studies of M. radiodurans were continued in order to elucidate the basis for the exceptional radiation resistance of this organism. One unusual feature discovered in M. radiodurans is the maintenance of multiple copies of the genetic information in each cell. This conclusion was reached from determination of the complexity of the genome and of the DNA content per cell in M. radiodurans. The complexity of the genome, i.e. the size of non-repetitive sequences, was determined from DNA renaturation kinetics to be approximately 2×10^9 daltons. The DNA content per cell varies with growth rate from 2.2×10^{10} daltons for fast growing cells to 9×10^9 daltons for extremely slow growing cells. Thus a minimum of 4 genome equivalents is maintained in each cell.

Wiegle reactivation (W-reactivation), previously called UV reactivation, is being studied in Acinetobacter calcoaceticus. W-reactivation is the increased survival of irradiated bacteriophage on host cells irradiated prior to infection. Two A. calcoaceticus phages were studied. After irradiation they survived loo and lo times better, respectively, when assayed on bacteria preirradiated to give 25% survival. One of the phages showed a further increased survival when assayed on bacteria which had been incubated in growth supporting medium after irradiation.

The data are compatible with the hypothesis that irradiation of bacterial cells induces synthesis of proteins active in the repair of radiation damage. This possibility is currently under study.

b. Production and Supply of Microbiological Standard Preparations and Biological Indicators

The laboratory produced, supplied and assayed standard preparations of the spore former Bacillus cerius, strain C 1/1, as well as of the vegetative Acinetobacter calcoaceticus, strain OA4. Tests of the microbiological efficiency of Danish radiation facilities were performed.

c. Customer Service for Hospitals, Research Laboratories and Industry

The following services were maintained:

- General consultation, irradiation of test specimens, evaluation of materials and packagings in relation to the introduction of new hospital equipment.
- irradiation of pharmaceutical materials and fodders in order to reduce the initial number of bacteria.

List of Publications

Accelerator Department Annual Progress Report. 1 January - 31 December 1976. Risø-M-19o9 (1977).

E.A. Christensen, Report on visit to National Centre for Radiation Technology, Cairo, Egypt, from January 13 to 26, 1977. Project No. EGY/73/o37-o3.

E.A. Christensen, Note on "Second International Conference on Radiation Sterilization of Medical Products", Vienna, Austria, April 25-28, 1977.

E.A. Christensen, Report on visit at Boris Kidrič Institute of Nuclear Sciences, Vinča, Beograd, Yugoslavia. November 26 - December 3, 1977.

E. Engholm Larsen, Driftsvejledning for ^{60}Co-bestrålingsanlægget placeret i Landbrugsafdelingen, bygning 3oo. Intern rapport juli 1977.

M. Gohn, N. Getoff and E. Bjergbakke, Radiation Chemistry Studies on Chemotherapeutic Agents. Part I. Pulse Radiolysis of Adrenalin in Aqueous Solutions. Journal of the Chemical Society, Faraday Transactions II, 1977, Vol. 73.

Johnny Hansen, Investigation of a High Voltage Hallow Cathode Electron Beam Source. Risø Report No. 359 (1977).

Mogens Trier Hansen, Multiplicity of Genome Equivalents in the Radiation Resistant Bacterium Micrococcus radiodurans. Accepted by J. Bacteriol., 1977.

P. Hedemann Jensen, J. Fenger and P. Broen Pedersen, Personsikkerhedssystemet ved Risø's lo MeV lineær elektronaccelerator. Risø-M-1948 (1977).

Jerzy Holcman, Formation and Reactions of Radical Cations of Substituted Benzenes in Aqueous Media. Risø-M-1947 (1977).

Jerzy Holcman and Knud Sehested, Dissociation of the OH Adduct of N,N-dimethylaniline in Aqueous Solution. J. Phys. Chem. 81 (2o) 1963-6 (1977).

W.L. McLaughlin, A. Miller, S. Fidan, K. Pejtersen and W. Batsberg Pedersen, Radiochromic Plastic Films for Accurate Measurement of Radiation Absorbed Dose and Dose Distributions. Radiat. Phys. Chem. lo 119-127 (1977).

W.L. McLaughlin, A. Miller and K. Pejtersen, Distribution of Energy Deposited in Plastic Tubing and Copper-Wire Insulation by Electron Beam Irradiation. Accepted by Rad. Phys. Chem., 1977.

S. Molin, K. von Meyenburg, O. Måløe, M. Trier Hansen and M.L. Pato, Control of Ribosome Synthesis in Escherichia coli: Analysis of an Energy Source Shift-Down. J. Bacteriol., Vol. 131, No. 1, 7-17 (1977).

K. Sehested, J. Holcman and E.J. Hart, Conversion of Hydroxycyclohexadienyl Radicals of Methylated Benzenes to Cation Radicals in Acid Media. J. Phys. Chem. 81 (14) 1363-7 (1977).

Roberto M. Uribe Rendón, Secondary Methods in Dosimetry. (Work done during a short stay at the Accelerator Department, Research Establishment Risø, 1976). Instituto de Fisica, UNAM, Mexico 2o, DF, 1977.

Conference Contributions

Jerzy Holcman, "Miller Conference", Portmeirion, North Wales, England. 28 March - 1 April, 1977.

Jerzy Holcman, Radical Cations of Substituted Benzenes in Aqueous Media. Danmarks tekniske Højskole, Copenhagen. 16 September 1977. (Thesis).

Jerzy Holcman, Anvendelse af strålingsteknik til studiet af organiske frie radikaler. Danmarks tekniske Højskole, Copenhagen. 23 September 1977. (Thesis).

5. Danish-Polish Symposium on Radiation Chemistry, Svaleholm, Risø, lo - 13 October 1977:

Krzysztof Bobrowski, New reactions of O_2^- detected by pulse radiolysis.
Jan Grodkowski, Pulse radiolysis of frozen crystalline alkaline systems with inorganic and organic cations.
Elżbieta Jaworska, New aspects of radiation-induced cross-linking of polyethylene in the presence of acrylic acid.
Przemysław Pańta, Calorimetry of single pulses of lo MeV and 13 MeV electrons in Zerań Linac.
Wacław Stachowicz, Free radicals in the radiolysis of geometric isomers of unsaturated hydrocarbons.
Zofia Stuglik, Pulse radiolysis of neutral iron /II/ solutions.
Stanisław Włodek, Ion-molecule reactions in the gaseous systems containing NO_2 studied by high-pressure mass spectrometry.

Walter Batsberg, Radiation induced cross-linking of poly(1,2-butadiene).

Hilbert Christensen, Pulse radiolysis at high temperature and high pressure.

Eva S. Floryan, Reactions of OH-radicals with some phenanthrolinemetal complexes and their role in a solar energy storage system.

Jerzy Holcman, Acid-base properties of aromatic radical cations in aqueous medium.

Niels Henrik Jensen, Pulse radiolysis of chlorophyll a.

O. Lang Rasmussen and Erling Bjergbakke, Simulation of chemical reactions by numerical integration.

Arne Miller, Dose distribution in irradiated wire insulation.

Ole Mogensen, Spur electron reactions studied by positronium formation measurements.

Dvora Berenstein, Bacteriological Control of Radiation Sterilization Plants. Risø, 26 October 1977.

Hanne Corfitzen participated in the Uran Pilot U.P.1 experiment. 1 September 1976 - 1 March 1977.

K. Sehested acted as the faculty opponent at the public defense by Dr. Torbjørn Reitberger of his doctoral dissertation entitled "The Radiolysis of Cyclic Hydrocarbons studied by Steady State and Pulsed Irradiation Technicques". Kungl. Tekniska Högskolan, Stockholm, Sweden, 18 May 1977.

Jerzy Holcman was awarded the degree of lic.tech. (corresponding to a PhD). His dissertation was entitled "Formation and Reactions of Radical Cations of Substituted Benzenes in Aqueous Media". Danmarks tekniske Højskole, 16 and 23 September, 1977.

The Accelerator Department arranged the 5. Danish-Polish Symposium on Radiation Chemistry at Svaleholm, 1o - 13 October 1977.

Customer Service for Hospitals, Research Laboratories and Industry

Test-irradiations were carried out for:

Alfred Benzon A/S, Copenhagen
Biofac A/S, Copenhagen
Bispebjerg Hospital, Copenhagen
Centralsygehuset, Nykøbing Fl.
Fibiger-Laboratoriet, Copenhagen
Finseninstitutet, Copenhagen
Frederiksborg Amts Centralsygehus, Hillerød
Kolding Sygehus, Kolding
Københavns Amts Sygehus, Glostrup
Københavns Tandlægehøjskole, Copenhagen
Novo Industri A/S, Bagsværd
A/S Nunc, Kamstrup, Roskilde
Patologisk Anatomisk Institut, Copenhagen
Polyteknisk Læreanstalt, DtH, Lyngby
Radiation Dynamics Ltd., South Marston, England
Rigshospitalet, Copenhagen
Planteavlsleder V. Schelbeck, Agedrup
Slagteriernes Forskningsinstitut, Roskilde
Uppsala Universitet, Fysiologisk Botanik, Uppsala, Sweden
Århus Universitet, Botanisk Institut, Risskov
Århus Kommunehospital, Århus.

Staff of the Accelerator Department

31 December 1977

Academic Staff

D. Berenstein
E. Bjergbakke
J. Fenger
M. Trier Hansen
J.W. Hansen
J. Holcman
B. Lynggård
A. Miller
K. Sehested

Technical Staff

S. Bøjlund Andersen
M. Elm Andersen (until 1 August 1977)
K. Bøysen
H. Corfitzen
I. Hansen
I. Høegh (from 1 October 1977)
T. Johansen
E. Engholm Larsen
F. Larsen
I.M. Larsen
L. Nielsen
W. Nielsen
P. Broen Pedersen
K. Pejtersen
B. Thomsen
M. Wille

Office Staff

E. Haugaard
R. Madsen

Consultants

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

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

Dr. W.L. McLaughlin, X-Ray Physics Section, Center for Radiation Research, National Bureau of Standards, Washington, D.C., U.S.A.

Visiting Scientists

Dr. Svetlana Sabovljev, Boris Kidrić Institute of Nuclear Sciences, Vinća, Beograd, Yugoslavia. (IAEA, 1 November 1976 - 1 February 1977).

Professor I. Draganić and Dr. Z. Draganić, Boris Kidrić Institute of Nuclear Sciences, Vinća, Beograd, Yugoslavia. (9 December 1976 - 1 April 1977).

Lektor Ulrik Kläning, Kemisk Institut, Århus Universitet. (25 January - 4 February and 1 - 3 June 1977).

Dr. E.J. Hart, Port Angeles, WA., U.S.A. (21 February - 11 March 1977).

Dr. L. Gazso, Frédéric Joliot-Curie National Research Institute, Budapest, Hungary. (2 - 6 May 1977).

Dr. M. Barić, Ruder Bosković Institute, Zagreb, Yugoslavia. (2o - 24 June 1977).

Drs. K. Bobrowski, J. Grodkowski, E. Javorska, W. Stachowicz, Z. Stuglik and S. Wlodek, Institute of Nuclear Research, Warsaw, Poland. (1o - 13 October 1977).

Dr. W.L. McLaughlin, National Bureau of Standards, Washington, D.C., U.S.A. (12 - 26 October 1977).

Professor Z.P. Zagorski, Institute of Nuclear Research, Warsaw, Poland. (6 November - 4 December 1977).

Civ.ing. H. Lønholt, Aase Møller and A. Christensen, Novo Industri A/S, Copenhagen.

Dr. Enrique Marino, Comision Nacional de Energia Atomica, Buenos Aires, Argentina.

Drs. G. Brown and M. Defrenne, Travenol International Services Inc., Brussels, Belgium.

Dr. Michael S. de Wilton, Radiation Dynamics, Ltd., South Marston, Swindon, Wiltshire, England.

Drs. Janos Dobó and Iván Kälmán, Research Institute for the Plastics Industry, Budapest, Hungary.

Dr. S. Rösinger, Hoechst AG, Frankfurt/Main, Germany.

Dr. F.H. Vogt, Stanford, Conn., U.S.A.

Dr. Z. Zaritsky, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

Dr. C. Woldringh, Laboratorium voor Electronen Microscopie, Amsterdam, Holland.

Dr. Lars Nauclér, Gambro AB, Lund, Sweden.

Drs. H.C. Alsted Nielsen and V. Johansen, F.L. Smidth & Co. A/S, Copenhagen.

Dr. Johan Lind, Royal Institute of Technology, Stockholm, Sweden.

Dr. Antoni Jówko, University Teacher College, Siedlce, Poland.

Civ.ing. P. Lausen, Stærkstrømsafd., Danmarks tekniske Højskole, Copenhagen.

Irradiation Facilities at the Accelerator Department

Electron Accelerators

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

Specifications:

Electron energy .... 1o MeV
Average electron current .... 1 mA
Peak electron current at 1o MeV .... 11oo mA
Pulse length, normal mode .... 1 - 4 µs
Pulse length, short pulse mode .... 1o - 1oo ns
Pulse repetition rates .... single pulses and
12.5, 25, 37.5, 5o, 1oo, 15o and 2oo 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 1o 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 4o cm providing a process irradiation capacity of 1ooo - 15oo Mrad kg/hour.
2. A horizontal beam, full beam peak power, for electron and X-ray irradiation.
3. A horizontal beam, reduced beam power (12.5 pps) in connection with a ± o.5% beam slit.

Target room beam facilities:

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

2. Field Emission Electron Accelerator, Febetron Model 7o5B

Specifications:

Electron energy	o.5 - 2.o MeV
Peak electron current	4ooo A
Pulse length (electron mode)	2o ns

3. Low-Energy Electron Accelerator, High Voltage Eng. Corp., Model EPS 4oo-IND

Specifications:

Electron energy	4oo keV
Electron current	5o mA
Scan width	12o 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,ooo mm and diameters of maximum 18o, 1oo, or 6o mm. The corresponding maximum dose rates (6,ooo Ci, 1 January 1978) are 3.3×10^5 rads/h, 8.8×10^5 rads/h, and 2.1×10^6 rads/h, respectively.

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

Designed for laboratory use and fitted with a 123 mm$^{\varnothing}$ x 15o mm irradiation chamber. The dose rate in the centre of the chamber (4,1oo Ci, 1 January 1978) is 3.5×10^5 rads/h. The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

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

Designed for laboratory use and fitted with a 12o mm$^{\varnothing}$ x 2oo mm irradiation chamber. The dose rate in the centre of the chamber (1,9oo Ci, 1 January 1978) is 1.9×10^5 rads/h.