7. Hildebrand, F. B., "Methods of Applied Mathematics," pp. 237-44, Prentice-Hall, New York (1952).

8. Kramers, H., and G. Alberda, *Chem. Eng. Sci.*, **2**, 173 (1953).

9. Rushton, J. M., *Chem. Eng. Progr.*, **50**, 587 (1954).

10. ———, and J. Y. Oldshue, *ibid.*, **49**, 161, 267 (1953).

11. Sachs, J. P., and J. H. Rushton, *ibid.*, **50**, 597 (1954).

12. Van de Vusse, J. G., *Chem. Eng. Sci.*, **4**, 178, 209 (1955).

13. Walker, O. J., Jr., and A. Cholette, *Pulp Paper Mag. Can.*, **59**, 113 (1958).

CHEMICAL ENGINEERING PROGRESS SYMPOSIUM SERIES ABSTRACTS

The Chemical Engineering Progress Symposium Series is composed of papers on specific subjects conveniently bound in individual books, which are published at intervals. The books are 8½ by 11 inches, paper covered, and cost $3.50 to members, $4.50 to nonmembers. They may be ordered from the Secretary's Office, the American Institute of Chemical Engineers, 25 West 45 Street, New York 36, New York.

The *A. I. Ch. E. Journal* will publish, from time to time, abstracts of the articles appearing in the Symposium Series volumes. Recently published volumes are abstracted below.

NUCLEAR ENGINEERING—PART VI, Vol. 55, No. 23, 1959.

A Digital Program to Evaluate Transients for Nuclear Power Plant Design, F. J. Scheib and A. J. Arker. The design limitations of a nuclear power plant for mobile use often depend on the transients which the plant undergoes during normal or casualty operation. Examples of decisions which depend on transient evaluation in the design of a pressurized water plant are given, and the model digital computer program used to analyze such transients is described. Important features of this program are nonsymmetrical and variable flow operation of the two coolant loops, use of nonanalytic input data, and flexibility for alteration. **Control of the PRTR-A Gas-Balance Method With Supplementary Mechanical Shims,** J. F. Fletcher. The Plutonium Recycle Program, a comprehensive research and development program, has as its goal the development of safe, economical methods of using plutonium fuels in power reactors. The Plutonium Recycle Test Reactor is a test facility essential to this program designed to have a high degree of versatility and to be capable of operating under a great variety of experimental conditions. The control system used provides an unusual degree of reactor safety. **A Study of the Feasibility of a Tracer System for Locating a Fuel-Element Failure in a Pressurized Water Reactor,** Meyer Pobereskin, Duane N. Sunderman, Aaron Eldridge, George D. Calkins, and Walston Chubb. This investigation indicated that a system of tracer elements for location of fuel-element failure merited development. The method consists in adding small amounts of different pairs of elements to the fuel alloy of each subassembly. When a fuel-element failure occurs, a portion of the coolant is analyzed radiochemically for the elements added to the fuel as tracers. The radioactive species of the elements detected indicate the subassembly in which the failure has occurred. Eleven elements were found to be suitable tracers. **Coolant Temperature Rise in a Pressurized Water Reactor During a Loss of Flow Incident,** Joel Weisman, Shepard Bartnoff, and G. C. Tirellis. A method is described for calculating the coolant temperature at the reactor outlet as a function of time following a loss of pumping power and the consequent loss of coolant flow. The effects of negative temperature coefficient and delayed gamma radiation on the heat production rate of the reactor are considered and contributions to the total coolant temperature rise calculated from both the nucleate boiling region and the nonnucleate boiling region of the core. **Reprocessing Costs for Fuel From a Single-Region Aqueous Homogeneous Reactor,** A. C. Jealous and R. J. Klotzbach. The cost is estimated for a fuel-reprocessing plant to recover fissionable, fertile, and moderator materials from irradiated slurry fuel of the Pennsylvania Advanced Reactor (PAR). The estimate is based on a reprocessing plant designed to process 47 kg. of thorium per day for return to the reactor plant. Off-site solvent-extraction decontamination of PAR fuel in A.E.C. multipurpose plant would cost more than complete-on-site reprocessing. **Pilot Plant Fluorination of Uranium Fuel Elements by Bromine Trifluoride,** Gerald Strickland, F. L. Horn, and Richard Johnson. The dissolution of uranium in bromine trifluoride at 250°F. was investigated in continuous equipment on a pilot plant scale. In particular the autocatalytic effect of the UF_6 concentration on the dissolution time of unirradiated B.N.L. reactor slugs was determined. A series of nine runs is described in which the UF_6 concentration progressed from 0 to 4.5 mole %. **Reprocessing Uranium-Zirconium-Alloy Reactor Fuel Elements,** C. B. Leek, R. B. Lemon, and F. K. Wrigley. The process employed for the recovery of uranium from uranium-zirconiumalloy reactor fuel elements at the Atomic Energy Commission's Idaho chemical processing plant is described, and the results of the initial processing and decontamination operations are summarized. **Effect of Geometrical Shape on the Continuous Dissolution of Aluminum in Mercury-Catalyzed Nitric Acid,** A. F. Boeglin and J. A. Buckham. The results of a study of the effect of geometrical shape of aluminum-reactor fuel elements on the dissolution rate in mercury-catalyzed nitric acid are presented. Statistical analysis of the data showed that the main effects, feed rates, catalyst concentration, and shape, and all first-order interaction effects had a significant effect on dissolution rate. A mathematical relationship between dissolution rate and feed rate, catalyst concentration and the catalyst concentration by feed-rate interaction was graphically developed for each shape. **General Economics of Chemical Reprocessing Using Solvent Extraction Processing,** F. L. Culler, Jr. The competitive requirement of producing electricity at 8 mills/kw.-hr. in the United States places limitations on the over-all recycle costs of irradiated fuel and fertile material. Based on buy-back prices published by the A.E.C. the residual value of fissionable and fertile material in irradiated fuel is almost always greater than the cost of recycle. Reprocessing probably will always be required.

NUCLEAR ENGINEERING—PART VII, Vol. 55, No. 27, 1959

Radiochemical Research in the U.S.S.R., Victor Spitsyn. A survey of the state of the art in the U.S.S.R. from the time of initial studies of radioactive elements soon after the discovery of radioactivity to the present (date of article is 1958). **The Use of Tracer Atoms in the Physicochemical Study of Some Inorganic Polycompounds,** Victor Spitsyn. Tracer atoms were used to ascertain in the primary stages of formation of aquopoly and heteropoly compounds, and to study their properties and structure by isotopic exchange, and other physical and chemical methods of research. It has been suggested that the process of formation of aquopoly and heteropoly compounds is related to the appearance of hydrogen bonds between the anions of acids, which participate in the said interaction. The existence of oxonium groups in the structure of aquopoly anions may also be assumed. **Effect of Gamma Radiation Intensity on the Polymerization of Ethylene,** B. G. Bray, R. A. Carstens, O. A. Larson, J. J. Martin, and K. K. G. Sikchi. In the field of photochemical reactions it is suggested that the reaction-rate constant often varies as the square root of the intensity of the radiation field. For the two-step mechanism proposed in this study it was found that the initiating reaction constant was directly proportional to the intensity of radiation. A secondary reaction constant was found. **Blast Effects Tests of a One-Quarter-Scale Model of the Air Force Nuclear Engineering Test Reactor,** Wilfred E. Baker. The results of a series nuclear accidents to a one-quarter scale model reactor simulated by explosives and propellants are presented. The accuracy of simulation of these power excursions and the applicability of laws of scaling blast loading and corresponding transient structural response are discussed. **Heavy-Water Reactors for Power Production,** David P. Herron. From a nuclear standpoint, heavy water is the most attractive moderator for thermal reactors because its high moderating ratio permits excellent fuel economy. The principal factors affecting the fuel-cycle and capital in design of heavy-water reactors are reviewed, and several possibilities for reducing the power cost of this type of reactor are discussed. **Conversion of Uranium Hexafluoride to Uranium Tetrafluoride,** S. H. Smiley and D. C. Brater. The atomic energy program has a need for large quantities of uranium metal and uranium salts of various uranium-235 assays for nuclear reactors. Since enriched uranium is usually available as the hexafluoride, it is necessary to convert this compound to uranium tetrafluoride as an intermediate step in the preparation of most of the desired reactor fuel materials. Contrary to published literature the single-step reduction of UF_6 to UF_4 with hydrogen was found to be quantitative; further a highly efficient, safe, economical was developed and adapted for large-scale production use. **High-Temperature Processing of Molten Fluoride Nuclear Reactor Fuels,** Warren R. Grimes, James H. Shaffer, Newman V. Smith, Richard A. Strehlow, Wilfred T. Ward, and George M. Watson. The removal of certain undesirable fission-product fluorides from reactor fuels consisting of molten mixtures of uranium tetrafluoride with other fluorides has been successfully accomplished in small-scale experiments by precipitation techniques which may be adaptable to large-scale application. Data relating to the solubility of xenon and other rare gases are presented and are pertinent to the ease of removal of such gaseous fission-product poisons. **Summary Report: Economic Comparison of Zircaloy and Stainless Steel in Nuclear Power Reactors,** Manson Benedict. In most nuclear reactors being designed for commercial power production, it is technically feasible to use either stainless steel, zirconium, or one of its alloys as structural material, fuel cladding, or fuel diluent. When zirconium is used within the neutron flux of the reactor, its low neutron-absorption cross section gives zirconium an important economic advantage over stainless steel. On the other hand, zirconium and its alloys cost more. This study was made to assist reactor designers in determining when it is advantageous to consider zirconium. **Boiling-Heavy-Water Reactor for Process Steam and Power,** Patrick J. Selak and George B. Humphreys. For a hypothetical reactor plant located in the United States there is no significant difference in tthe net fuel cycle cost or the cost of steam produced, whether the reactor is operated with fuel element reprocessing or on a throw-away basis. This suggests the suitability of this reactor for remote mining and processing operations. **Laboratory Facilities for Nuclear Engineering Education at MIT,** T. J. Thompson. A comprehensive program of graduate study in nuclear engineering is intended primarily for students with undergraduate degrees in physics, chemistry, or metallurgy or chemical, civil, electrical, or mechanical engineering. For those interested in specializing in nuclear engineeering, the program leads to the degree of M.S. in nuclear engineering or Sc.D. Courses taught are outlined. **Conceptual Design of Pyrometallurgical Reprocessing Plant,** Louis Basel and Joseph Koslov. A pyrometallurgical reprocessing plant for handling fuel from a 500-Mw. fast-breeder reactor is described. Also included are capital and operating costs and a discussion of problems requiring further investigation. **The Nitrophos Extraction Process for the Separation of Zirconium and Hafnium,** Wayne H. Keller and Irwin S. Zonis. The several possible systems for separating *Zr* and *Hf* are reviewed briefly. The reasons for selecting the Nitrophos liquid-liquid extraction process are discussed. The laboratory and pilot plant experiments are described and the data presented. Under the conditions studied, reactor-grade zirconium can be prepared in a column with less than ten theoretical stages. The commercial plant design is described and preliminary operating results are given. **Natural-Circulation Boiling Reactor With Tapered Coolant Channels,** S. G. Bankoff. It is suggested that some of the heat transfer characteristics of natural-circulation boiling reactors might be improved by employing tapered coolant channels. A previously developed flow model for straight channels is used to predict frictional losses in tapered channels with uniform and with cosine heat-flux distributions. **Temperature Rise in Underground Storage Sites for Radioactive Wastes,** R. S. Schechter and E. F. Gloyna. An attempt is made to determine the limits of the temperature increase resulting from the release of energy by high-level radioactive wastes stored in underground spherical cavities. This determination is accomplished by calculating the temperature rise on the basis of two models, one fixing the upper limit of temperature increase and the other the lower limit. The results of these calculations are presented in a generalized graphical form to facilitate design calculations. **A Technical and Economic Analysis of the Separation of Plutonium and Fission Products from Irradiated Nuclear Reactor Fuels,** H. A. Ohlgren, J. G. Lewis, M. E. Weech, and G. W. Wensch. The technical background for chemical processing of irradiated nuclear reactor fuels is discussed, and aqueous solvent extraction methods for the separation of uranium from plutonium and fission products are briefly described. Estimated capital and operating costs are presented for an aqueous separation of plutonium and fission products from irradiated fuel elements of a fast-breeder power reactor.

REACTION KINETICS AND UNIT OPERATIONS,

Vol. 55, No. 25, 1959

Reaction Rates in Chemical Engineering Science, Hugh M. Hulburt. Chemical reactions consist in the redistribution of electrons between nuclei. The laws which govern their interactions are concisely summarized in the Schrfidinger equation and the postulate of Coulomb's law for the force between charged particles. **Transport Processes With Chemical Reactions,** Stephen Prager. The general transport equations, after discussion, are applied to (1) reactions with bulk flow only, (2) reactions accompanied by diffusion and heat conduction, both with and without the assumption of local chemical equilibrium, (3) diffusion-controlled surface reactions, (4) systems in which reactions give rise to volume changes, and (5) the steady state. For systems with nonlinear kinetics the method of moments is shown to give good results with a relatively small amount of effort **Turbulent Transport in Chemical Reactors,** John Beek, Jr., and R. S. Miller. To predict the behavior of a reactor under specified conditions, one must be able to calculate not only the rates of whatever chemical reactions are going on but also the rates of whatever transport processes are involved. This paper lists and discusses the transport processes. **Intraparticle Diffusion in Catalytic Systems,** Paul B. Weisz. Diffusion transport may have various effects on the measured rate of conversion. Application of diffusion equations to chemical rate processes is discussed, and examples of various cases of intraparticle chemical conversion and generally useful methods of evaluating diffusion effects are given. Diffusion-transport criteria can often be used to investigate reaction kinetics involving intermediate species. **Stability of Chemical Reactors,** C. H. Barkelew. It has been common practice to base the stability aspects of reactor design primarily on pilot plant or laboratory experience. Recently, however, several analyses of the thermal behavior of reactors have been published in the hope that a suitable theoretical treatment could save expensive experimentation. This paper presents a new method of designing stable tubular reactors. **Chemical Reaction-System Dynamics,** Alan S. Foss. Recent developments in the dynamics of chemical-reaction systems contributing toward improved control of today's chemical processes are reviewed in some detail, with emphasis on the methods and techniques of analysis, and some means of filling the gaps in our present knowledge are suggested. **Progress in the Fundamentals of Heat Transfer,** M. T. Cichelli. Progress in heat transfer science during the past fifty years is briefly reviewed, with emphasis on those developments which have had the greatest impact on chemical engineering practice in this country. **Future Trends in Heat Transfer Technology,** Donald Q. Kern. Future developments in thermal process technology will be derived from the design practices employed in nuclear reaction, cryogenics, rocketry, missile technology; from extensions of current chemical engineering techniques; and from the adaptation of advanced mathematical tools to computer solutions. Rockets and related problems predominate in outmoding current thermal processing concepts. **Mass, Heat, and Momentum Transfer Between Phases,** T. K. Sherwood. Mass may be transferred, as by evaporation of a liquid into a gas in a wetted-wall tower; heat is transferred if tube and fluid are not at the same temperature; and momentum transfer from the fluid results in a shear stress at the tube wall, causing a decrease in fluid pressure along the tube length. The subject of the present paper is the interrelationships of these three transfer processes. **Progress in Fractional Distillation,** R. L. Geddes. A brief outline of important developments that contribute to present knowledge of design of fractionators is given in historical sequence. Some comments on the present status and future problems from a chemical engineer's viewpoint are offered. **Liquid-Liquid Extraction: Theory and Practice,** Robert B. Beckmann. In this presentation of, the theory and practice of solvent extraction—its history, current practice, and a few prognostications for the future—the enormity of the general field has limited discussion of the fundamentals of mechanism and theory as they pertain to liquid-liquid extraction in general and specifically to presently popular commercial extraction equipment. **Progress in Separation by Sorption Operations—Adsorption, Dialysis, and Ion Exchange,** G. P. Monet and Theodore Vermeulen. The object of this paper is to outline briefly the present status of quantitative knowledge about adsorption, dialysis, and ion exchange. First, general effects which are believed to apply to all three fields are discussed, and then are considered specific effects which are caused by the sorbent materials used. **Principles of Gas-Solids Separations in Dry Systems,** S. K. Friedlander. The mechanics of fluid-particle systems are used to explain the functioning of each class of device developed to handle the wide range of problems encompassed within suspension concentrations and particle-size limits. Emphasis is on recent advances in the field and on areas which may prove fruitful for further research. **The Art and Science of Liquid Filtration,** H. P. Grace. This paper describes the present state of theoretical knowledge as applied to solution clarification and to cake filtration and its limitations, considers the major problems in measurement techniques and their potential solutions, and points out the potential areas of development that are most likely to yield significant improvements in filtration performance. **Separation by Crystallation,** Robert A. Findlay and Dwight L. McKay. Crystallization could be the basis of a separation method of wide usefulness, particularly in the field of organic chemicals, as it minimizes the decomposition of heat-sensitive substances and separates organic isomers which can be separated practically in no other way. Application has been hindered by lack of chemical engineering development. **Mixing of Liquids,** J. H. Rushton and J. Y. Oldshue. Mixing of fluids in chemical processing usually involves an intimate and homogeneous distribution of all liquid components, gases, and particulate solids which may be involved. The most common device to bring about

(Continued on page 3J)

(*Continued from page 352*)
mixing is some form of rotating impeller, driven by a shaft attached to a power-transmission device connected to an electric of other motor. **Mixing of Solids,** Sherman S. Weidenbaum. High lights of solids-mixing studies are given, based on a critical and interpretive review of American and foreign literature and other pertinent material. Degree of mixing, theoretical frequency distributions, rate studies, and equipment are discussed. Areas for future investigation are suggested. **Size Reduction,** Lincoln T. Work. The creation and control of particle size goes under many names, some pointing to the production of particles in a desired range of sizes. This paper will discuss the aspects of solids only, with particular reference to size reduction and some reference to size enlargement. **Drying—Its Status in Chemical Engineering in 1958,** W. R. Marshall, Jr. Historically, drying is one of the oldest operations in chemical engineering, and yet at this date its theoretical development has not progressed so far as many other chemical engineering operations. The objectives of a drying operation can be manifold, and it is difficult to name a common objective, other than moisture removal. Consequently, drying problems generally involve a variety of secondary objectives.

Errata

The equations given below are corrected versions of those published in "Heat Transfer in Cylinders with Heat Generation" by Leonard Topper, *A.I.Ch.E. Journal,* 1, 463 (1955). The help of Dr. P. J. Schneider and of Professor R. Byron Bird is acknowledged by the author.

$$\frac{t - t_s}{t_0 - t_s} = \sum_{n=1}^{\infty} N_n J_0(\lambda_n w) e^{-\lambda_n^2 (\alpha/sV)(x/s)} + \frac{Bs^2\left(1 + 2\frac{k}{sh} - w^2\right)}{4\alpha(t_0 - t_s)} \qquad (7)$$

$$\frac{t - t_s}{t_0 - t_s} = 1 = \sum_{n=1}^{\infty} N_n J_0(\lambda_n w) + \frac{Bs^2\left(1 + 2\frac{k}{sh} - w^2\right)}{4\alpha(t_0 - t_s)} \qquad (11)$$

$$N_n = \frac{2\frac{hs}{k}}{\left[\lambda_n^2 + \left(\frac{hs}{k}\right)^2\right] J_0(\lambda_n)} \left[1 - \frac{Bs^2}{\alpha\lambda_n^2 (t_0 - t_s)}\right] \qquad (12)$$

$$\frac{t - t_s}{t_0 - t_s} = \frac{Bs^2\left(1 + 2\frac{k}{sh} - w^2\right)}{4\alpha(t_0 - t_s)} + 2\frac{hs}{k} \sum_{n=1}^{\infty} \frac{J_0(\lambda_n w) e^{-\lambda_n^2 (\alpha/sV)(x/s)}}{\left[\lambda_n^2 + \left(\frac{hs}{k}\right)^2\right] J_0(\lambda_n)} \left[1 - \frac{Bs^2}{\alpha\lambda_n^2 (t_0 - t_s)}\right] \qquad (13)$$

$$t + \frac{B}{A} = \left(t_s + \frac{B}{A}\right) \frac{J_0\left[\left(\frac{As^2}{\alpha}\right)^{1/2} w\right]}{J_0\left[\left(\frac{As^2}{\alpha}\right)^{1/2}\right]}$$