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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

NOVEMBER 1962

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Oak Ridge, Tennessee
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OAK RIDGE NATIONAL LABORATORY

STATUS AND PROGRESS REPORT

NOVEMBER 1962

This Status and Progress Report summarizes the unclassified portion of the Laboratory's work. Some of the topics are included every month, but the majority are reported on a bimonthly schedule.

REACTOR DEVELOPMENT PROGRAM

GAS-COOLED REACTOR PROGRAM

EGCR Components. – Two hundred and seventy-three EGCR fuel assemblies have been produced, and over 200 of these have passed final inspection. There have been 4753 fuel element rods manufactured to date, and 21,000 lb of UO_2 has been accepted out of a total requirement of approximately 33,000 lb. A final inspection review was conducted at the Speer Carbon Company, and sufficient graphite sleeves were accepted to fulfill requirements, with an overage of 45 sleeves. The ORNL Criticality Committee approved the shipping of 16 assemblies in one container, but it may be necessary to have them shipped by an AEC carrier.

Welding of the casings of the EGCR main blowers and vessel cooling compressors continued, and shop and plant procedures for testing the blowers are being reviewed. All stainless steel welding and virtually all carbon steel welding were completed for the lower chase piping for experimental loops TS-2, TS-3, and TL-4. The mechanical and pressure tests for a prototype bottom loop closure were found to be satisfactory, and the subcontractor was authorized to proceed with the manufacture of parts for the production closures. The assembly of the EGCR control-rod-drive testing facility was completed except for the control panels, which are now being subjected to final equipment performance checks.

EGCR Physics. – Infinite-medium neutron-multiplication factors are being calculated for the EGCR and for the British AGR, using, on the one hand, free-gas scattering kernels for the graphite to establish the neutron spectrum, and, on the other hand, scattering kernels derived for the actual polycrystalline graphite. The crystal-model calculations give k values several tenths of a percent lower than the free-gas model calculations, even for assumed moderator temperatures as high as 1200°K.

EGCR Graphite Surveillance. – A detailed description of the arrangement of graphite specimens in the surveillance channel was prepared. The graphite specimens will be contained in six vacant fuel assemblies and arranged in nine levels separated by graphite spacers. The six assemblies will be placed in channel 140, which is located in core column 270-65.

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This channel is near an instrumented fuel assembly but not near a control rod. Drawings were made showing the type, number, and arrangement of test specimens in each level.

GCR-ORR Loop No. 2 Operation and Experiment Design. – GCR-ORR loop No. 2 was operated continuously at low temperatures for 120 hr. The bypass purification system, the sampling system, and the gas chromatograph performed quite satisfactorily. The dead weights on the vacuum relief valves were replaced with springs to afford improved operation. Several possible hazards were reviewed, and it was found that there was a negligible probability of generating explosive gas mixtures in the cell. Design of the first fueled experimental assembly for testing graphite balls containing coated uranium carbide particles was completed, and fabrication was begun.

Irradiation Experiments in GCR-ORR Loop No. 1. – The No. 8 fuel element, which has a roughened surface formed by copper-brazing 0.0063-in.-diam wire with a 0.090-in. pitch on the surface of the stainless steel can, was removed from the loop after one reactor cycle. The element performed approximately as had been expected; however, there was an uncertainty in the measurement of the outlet gas temperature. A new element, designated 8S, was assembled for insertion in the loop. It is similar to element No. 8, except that the wire pitch is 0.040 in. and the element shroud has additional thermocouples for a better measurement of the outlet gas temperature. This element is scheduled for irradiation during two reactor cycles.

ORR Capsule Irradiations. – Irradiation of capsule 03-6, which contains vendor-made fuel of the EGCR lot, is continuing; the maximum cladding temperature is 1600°F. The capsule is scheduled for removal at the end of the current ORR cycle. Seven new capsules were assembled and are ready for insertion. These include one capsule of stainless-steel-clad $BeO-UO_2$, four additional specimens of vendor-made EGCR fuel, one cylindrical bushing-type graphite matrix element containing coated particles, and a capsule of a new design containing four coated-particle-fueled graphite spheres.

Postirradiation Examination of French Stainless-Steel-Clad Fuel Test Capsules. – Two fueled test capsules that were fabricated by the French CEA and irradiated in the ORR were examined. The capsules were 0.46 in. in diameter, and the type 347 stainless steel cladding was 0.014 in. thick. These capsules were irradiated at an external pressure of 850 psi and a cladding temperature of 1200°F. The burnup was approximately 7000 Mwd per metric ton of UO_2.

No changes in the capsules were apparent under visual examination. A small leak in the cladding of one capsule was indicated by bubble testing; however, subsequent examination showed that there was not sufficient leakage to permit the capsule to be filled with the NaK coolant or to allow significant escape of fission gas from the capsule. The gamma radioactivity scans indicated uniform burnup along the capsules, with no fuel shifting. With the exception of the expected collapse of the cladding onto the UO_2, there were no dimensional changes. Metallographic examination of selected fuel and cladding sections revealed no areas of potential failure. The cladding grain size was extremely fine (ASTM No. 10–11),

and there was no deformation at fuel-pellet interfaces. Some grain growth and void formation in the central regions of the fuel indicated that those areas had experienced a considerably higher temperature (~1600°C) than had been expected (~1000°C). A thin reaction layer was present at some areas on the inner surface of the cladding. No evidence of a stainless steel–UO_2 reaction had been observed previously at similar temperatures.

Instantaneous Fission-Gas Release from Coated Particles. – Capsule B9-9, which contained pyrolytic-carbon-coated uranium carbide particles of the NCC-AD duplex type, was irradiated at 800°F to a burnup of 9 at. % of the uranium. These particles were irradiated at 800°F to study irradiation damage to the particle coatings at low temperature. Fission-gas release rates increased to a detectable level shortly after irradiation began, but after equilibrium was reached the release rates remained nearly constant during the 82-day irradiation period. There was no detectable release-rate increase with burnup. The capsule was subjected to 42 thermal cycles caused by reactor shutdowns. The average fractional fission-gas release rates (R/B) for the five isotopes measured were: Kr^{87}, 0.6×10^{-5}; Kr^{88}, 0.8×10^{-5}; Kr^{85m}, 2.1×10^{-5} (calculated at a yield of 1%); Xe^{133}, 6.1×10^{-5}; and Xe^{135}, 1.7×10^{-5}. These rates are higher, by a factor of 2, than the average fractional release rates of the same type of particles irradiated to 15 at. % uranium burnup at 1500°F (capsule B9-8). Because there was no increase in fission-gas release with burnup, it seems likely that this capsule started with more broken coatings than capsule B9-8.

Preparation and Characterization of Coated Particles. – Four lots of coated and uncoated particles were received for evaluation and irradiation testing. Two lots from General Atomic are representative samples of pyrolytic-carbon-coated $(U,Th)C_2$ particles used in the fabrication of the fueled-graphite spheres. Batch GA-301 contained normal uranium and was used in the fabrication of two groups of control spheres designated GA-S3 and GA-S4. Batch GA-302 contained fully enriched uranium and was used in the fabrication of fuel spheres designated GA-S1 and GA-S2. Pyrolytic-carbon-coated $(U,Th)C_2$ particles and uncoated $(U,Th)C_2$ particles identified as 3M-119 and 3M-119U, respectively, were received from the Minnesota Mining and Manufacturing Company. These particles are representative of fuel for graphite spheres that are on order from this company.

Fueled BeO Coating Studies. – A method was developed for coating individual UO_2 fuel particles with essentially dry BeO powder. This method shows promise as a means for reducing or eliminating the exposed fuel on the surface of fueled BeO specimens. The process consists in rolling alcohol- or acetone-moistened spheroidal fuel particles (preferably green) in a cylinder and adding –100 mesh BeO powder ("conditioned" by atmospheric moisture) to the rolling particles. During processing the BeO adheres uniformly and almost completely to the fuel particles. The BeO-coated fuel particles can be formed into pellets with conventional dry-pressing techniques, and the resultant specimens have better fuel-particle dispersion and fewer exposed fuel particles on the surface than do specimens fabricated from mechanically mixed (blended) fuel and BeO.

Experimental Studies of Fission Product Deposition. – Further chemical analyses of the piping surfaces from the first run of the BMI fission

product deposition loop showed the presence of barium and traces of silver, in addition to the six elements mentioned previously (ORNL-3377, p 4).

Physics of High-Temperature GCR. – Fuel-cycle calculations for large, homogeneous, graphite-moderated reactors with U^{235} fuel and with thorium as fertile material continue to indicate that fuel-cycle costs are minimized by stressing long fuel burnups rather than high conversion ratios. For a reactor with 2% neutron leakage and an initial carbon-to-U^{235} ratio of 2000, a minimum fuel cost of 0.63 mill/kwhr is calculated for an assumed fabrication-plus-recovery cost of $10 per kg of uranium plus thorium. For this minimum-cost case, the fuel burnup is 1.2 fissions per initial fissile atom, the conversion ratio is 0.72, and the average power density is about 10 w/cm^3. If the assumed fabrication-plus-recovery cost is $1000/kg, the minimum cost of 1.15 mills/kwhr is achieved with a burnup of 1.9 fissions per initial fissile atom, a conversion ratio of 0.63, and an average power density of about 5 w/cm^3. Other fuel-to-moderator ratios are being studied, and the effect of recycling U^{233} is being examined.

Code Development. – The one-dimensional, cylindrical transport code SWAPS was revised to permit the use of arbitrarily wide mesh spacing. While the code remains rapidly convergent and fairly accurate, improvement in the agreement between calculated and theoretical estimates of critical radii is still needed.

Programming was started on a multigroup, two-dimensional program for rectangular, cylindrical, and polar coordinates. A special feature of this program is to be the solution of constant-source problems.

The group-rebalancing procedure was examined to see whether the method is generally applicable to a multigroup diffusion scheme. It was shown that, other than for obvious exceptions, which can be ruled out by programming precautions or preliminary inspection, no negative or zero driving factors will arise in pure down-scattering. For a general scattering matrix, the driving factors will be positive nonzero for two or three groups, but it is not yet known whether this is true for any number of groups.

STUDIES AND EVALUATIONS

Reactor Evaluation Studies. – The evaluation of the Babcock and Wilcox consolidated nuclear steam generator (CNSG) was completed. The proposed design had a reactivity lifetime of 320 full-power days (84 Mw of heat) for the first core and 355 days based on the equilibrium cycle; B&W obtained 360 days for both cases. The proposed core loading with three radial zones resulted in a maximum/average power density ratio of about 2.3, compared with 3.0 used by B&W. The calculated temperature and Doppler coefficients of reactivity were in good agreement with B&W values. The cost bases given in the AEC Cost Evaluation Handbook gave a fuel cycle cost of 3.84 mills/shp-hr for the first cycle and 2.63 mills/shp-hr for the equilibrium cycle; B&W reported 2.1 mills/shp-hr for the equilibrium cycle. The above difference was due largely to the different fuel fabrication costs considered ($90/kg vs $38/kg).

Additional reactor physics results were obtained for the large natural-uranium reactors being considered for water-desalinization plants; these were obtained by using the Expire program. Reactors fueled with nested tubular oxide-fuel elements, cooled by boiling H_2O, and moderated by a mixture of D_2O and graphite (20% graphite by volume) had reactivity lifetimes of about 7500 Mwd/ton when utilizing a 10-in. square lattice pitch. (Inclusion of power-flattening fueling schemes and poisons for power distribution control would lower the lifetime to about 5000 Mwd/ton.) A positive void coefficient of reactivity was associated with the H_2O coolant for this particular lattice. Replacing the graphite moderator volume with additional D_2O (99.6% D_2O) still gave a positive void coefficient. With heavy-water moderator (99.6% D_2O) and a 9-in. square lattice, the void coefficient was negative throughout the lifetime; the reactivity lifetime with natural UO_2 fuel was about 7000 Mwd/ton.

APPLIED AND BASIC REACTOR PHYSICS DEVELOPMENT

Basic Reactor Physics. — Experiments in which the large metal faces of two 8- by 10-in. uranium (93.2 wt % U^{235}) metal slabs were separated by various distances have shown that the critical thickness of each slab varies from 1.87 in. at a separation distance of 0.11 in. to 3.12 in. at a separation distance of 5 in. The prompt-neutron decay constants, measured by the Rossi α technique, varied from 1.08×10^6 to $\sim 8.9 \times 10^5$ sec^{-1} for separation distances from 0 to 1 in. and were then constant between 1 and 5 in.

Prompt-neutron decay constants in unreflected and reflected delayed-critical parallelepipeds of a homogeneous mixture of UF_4 and paraffin were determined by the pulsed-neutron technique. The fuel mixture had a density of 4.5 g/cc and contained 92 wt % UF_4 in which the U^{235} enrichment was 3%. The reflector was a 15-cm thickness of paraffin ($C_{25}H_{52}$) with a density of 0.93 g/cc. The measured values of the decay constant in unreflected and reflected assemblies are 344 ± 3 and 258 ± 2 sec^{-1} respectively. These are to be compared with 347 and 276 sec^{-1} calculated by S_n neutron transport theory with the 16-group cross section of Hansen and Roach.

REACTOR FUELS AND MATERIALS DEVELOPMENT

Nondestructive Test Development. — Recent studies in ultrasonics have been directed toward the use of two-crystal reflection techniques for the detection and evaluation of nonbonding in clad structures. Probes are being designed and fabricated for the inspection of the bonded interface between small-diameter tubing and a thicker annular section — that is, brazed tube-to-header heat exchanger joints. The two crystals within the probe serve as transmitter and receiver, respectively, for the ultrasonic energy, and are separated by an acoustic baffle to prevent reception of any sound except that which has passed through the cladding. If the braze is well bonded, little if any signal will be detected by the receiver crystal. If large nonbonds are present, a traveling wave vibration or

Lamb wave may be established in the cladding if the proper ultrasonic conditions are satisfied. Detection of nonbonds as small as 0.0007 in.^{2} has been demonstrated by a technique in which the refracted ultrasonic path length in the clad is a multiple of odd quarter-wavelengths. For either test the appropriate angular arrangement and frequency of the crystals are carefully selected to optimize the indications from the nonbonded areas.

Although the technique is applicable to any bonded joint between a thin clad and a thick base metal, much of the study has been directed toward such joints in heat exchangers. To this end, a mechanical device has been developed which will allow controlled uniform scanning of the joint. Data potentiometers attached to the mechanical motions and electronic gating of the signals allow automatic recording of nonbonded-area maps.

Mechanical Properties. – Previous studies have shown that nickel and several nickel-base alloys have less desirable high-temperature creep-rupture properties in a hydrogen environment than they do in an argon environment. Recent studies have been directed toward defining the mechanism or mechanisms responsible for this effect. Several meaningful results have been obtained.

1. Tests on electron-beam zone-refined nickel single crystals show that the creep properties of this material are deleteriously affected by hydrogen. Tests of this material in which the environment was periodically changed between argon and hydrogen showed that there is a characteristic creep rate associated with the material in each environment. Hence, it appears that the creep behavior is not influenced through alteration of the chemistry of the material caused by exposure to either environment.

2. The observation of void formation and growth during creep tests led to an investigation of the influence that environment could have on this process. It was reasoned that the rate of void growth due to vacancy condensation could be increased by an increase in either the concentration or mobility of vacancies. These factors also control the rate of self-diffusion in a pure metal. It was concluded from experiments in which the rates of diffusion of dilute quantities of Co^{60} in nickel were compared in argon and hydrogen environments that neither the concentration nor the mobility of vacancies is appreciably affected by environment.

3. Electron-transmission studies on nickel foils after creep testing in argon and hydrogen environments show a marked difference in the mobility of grown-in dislocations. The dislocations in the specimen run in argon cannot be made to move in the electron microscope, whereas those in the specimen run in hydrogen move readily. If the hydrogen is removed from the specimen run in a hydrogen environment by heating in vacuum at 200°C, the mobility of the dislocations is greatly reduced.

It is presently felt that the formation of "atmospheres" of hydrogen atoms about impurity atoms prevents them from being drawn into the stress fields of moving dislocations. When hydrogen is not present, the impurity atoms move to the dislocations and retard their motion. The apparent mobility of the impurity atoms at 200°C leads one to speculatively identify them as carbon.

Solid Reaction Studies. – Diffusion coefficients of Ti^{44} and V^{48} in the body-centered cubic beta phase of iodide titanium have been determined for the temperature range 900 to 1550°C. Resulting nonlinear Arrhenius-type plots of the data gave apparent activation energies varying from 30 to 45 kcal/mole for Ti^{44} and 32 to 50 kcal/mole for V^{48} at temperatures varying from 900 to 1550°C respectively. These results agree qualitatively with previous results on diffusion in body-centered cubic zirconium and may prove that nonlinear Arrhenius-type behavior is a general characteristic of volume diffusion in body-centered cubic metals.

Materials Compatibility Studies. – Past purification experiments have shown titanium sponge to be a suitable gettering agent for removing oxygen from potassium, owing to the favorable difference in the free energy of formation of potassium and titanium oxides and the large surface-area-to-weight ratio of the sponge. Recent work with titanium sponge has shown that magnesium in the titanium (normally 800 to 4000 ppm) can react with oxygen in solution in the potassium to form MgO particles. In these experiments the MgO concentration was sufficiently high and the particle size sufficiently large to plug 10-μ metallic filters in the transfer system. Such a condition is undesirable in systems using potassium as a heat transfer medium.

In attempts to circumvent MgO formation during the purification or ultimate use of potassium, two experiments were performed with titanium and zirconium foils used as gettering agents. The concentration of magnesium in foil is usually less than 50 ppm. The use of foil also facilitates the determination of the ratio of the getter surface area to the potassium volume, which is known to be an important test variable. The experiments were conducted with 4-mil foils fabricated into cylindrical configurations and contained in stainless steel purification vessels. Equilibration time and temperature were 24 hr and 760°C, respectively, and the ratio of the surface area of the getter to the volume of potassium was approximately 10:1. In these experiments, several thousand grams of potassium were used, and the oxygen concentration in each case was reduced from about 80 to about 20 ppm. The potassium, before and after testing, was analyzed by the mercury amalgamation method. The absolute values of the oxygen concentrations, however, are in doubt because the accuracy of the analytical technique, which is currently under investigation, is unknown. The fourfold change noted attests that purification occurs when titanium and zirconium foils are used for relatively short times, at low temperatures, and with moderate surface-area-to-volume ratios.

Fuel Element Development. – A program was initiated to study the pyrolytic deposition of metals and carbides. The prime objective is the direct fabrication of uranium carbide fuel modules with integral refractory-metal cladding and with both deposited from metal halides and hydrocarbons. To determine deposition rates of pyrolytic graphite from methane, a series of experiments was run with varying temperature, flow, and system pressure. It was found that deposition rates could be varied from 1 mil/hr at 1400°C to 23 mils/hr at 2000°C.

To evaluate the behavior of the system before operation with uranium hexafluoride, boron trichloride and tungsten hexafluoride were used. By additions of hydrogen and boron trichloride to methane, nonstoichiometric boron carbide (boron concentrations varying from 10 to 70%) was produced

at 1300°C at a rate of 11 mils/hr. The 70% B-30% C specimens have an estimated hardness of 9.5 on the Mohs' scale and show random orientation of the structure on x-ray diffraction analysis. On metallographic examination of the material, no structure can be detected.

Tungsten metal was deposited in the range 700 to 1100°C by decomposition of tungsten hexafluoride in the presence of hydrogen; the deposition rates were 11 to 40 mils/hr. Material deposited in the lower temperature range shows fine grains and random orientation; that deposited at higher temperatures is crystalline and highly oriented.

Samples of stoichiometric tungsten monocarbide are now being prepared, and system modifications for deposition of uranium carbide from uranium hexafluoride and methane are in progress.

REACTOR COMPONENTS DEVELOPMENT

Reactor Controls Development: Measurement of Shutdown Reactivity. — Preliminary experiments were performed at the BSR to determine the feasibility of measuring the shutdown reactivity of a reactor by the analysis of neutron fluctuations, or noise. Concurrent preliminary investigations were also made by Badgley (unpublished MS thesis, University of Florida), whose results were inconclusive. If the noise source is "white," the reactor noise power spectrum has the form of the square modulus of the reactor transfer function. According to a theory based on a point reactor model, the upper break frequency of the noise spectrum is a function of the magnitude of the negative reactivity of the reactor. By determining the break frequency, one then has a measure of the shutdown reactivity. Alternatively and more simply, the ratio of the spectral densities of two frequency intervals is also a relatively sensitive function of the subcriticality of a reactor.

An analyzer composed of six band-pass amplifiers, three quarter-square multipliers, and three time-averaging devices was assembled for making these studies. The analyzer measures the spectral densities in six fixed-frequency intervals in a few minutes. By use of the analyzer data, the shutdown reactivity can be determined by either of the two methods discussed previously.

Initial results at the BSR were sufficiently encouraging that further effort in this direction is being initiated. Improved apparatus requirements include a boron-coated ion chamber of low inherent noise, a wide-band amplifier having a low input noise (1 μv or less), and more convenient fixed-filter networks.

Reactor Controls Development: Development of a DC Operational Amplifier. — Development of a circuit for a dc operational amplifier was completed. This instrument is suitable for amplifying small currents in safety or control systems. The all-solid-state circuit utilizes a field-effect transistor as a high-impedance input stage. With an input capacitance (ion chamber plus cable) of 15,000 picofarads, the response time of the circuit is less than 100 μsec. The maximum useful sensitivity of the circuit is 2×10^{-8} amp, full scale, and the long-term drift and temperature stability are better than 0.1%. The circuit has provisions for changing its gain so that it can be continuously calibrated against a heat power signal.

Reactor Controls Development: High-Sensitivity Fission Counter. — By use of the parallel-plate configuration of the new multisection ionization

chambers (ORNL Q-2618), a high-sensitivity fission counter was built and tested. The U^{235} deposit is 1.0 mg/cm^2 on a 1000-cm^2 electrode surface area; the electrode spacing is 2 mm, and the gas filling is 2280 torr of 97% argon and 3% carbon dioxide. The counter has a sensitivity of 0.55 count/sec per $n\bar{v}$ at the pulse-height setting that corresponds to 0.1 count/sec of alpha background. At twice this pulse-height setting the neutron sensitivity is 0.37 count/sec per $n\bar{v}$. Special care was taken to avoid gamma pileup; the counter was tested in a hot cell in a gamma flux of 10^5 r/hr. With a preamplifier having double differentiation ($\tau = 0.15 \times 10^{-6}$ sec), the pulse-height setting required to have less than 0.1 count/sec of gamma pileup pulses reduces the neutron sensitivity by 5%.

Reactor Controls Development: Preamplifier Tests. — The preamplifier that is part of the flexible pulse preamplifier and fission chamber assembly (ORNL-3211, p 13) was tested while operating in stagnant air at 100°C and in flowing water at 100°C. For all conditions, the temperature of all components was 10°C or more below the maximum temperatures given by manufacturers' specifications. No change in preamplifier gain or pulse shape was observed.

POWER REACTOR FUEL PROCESSING

Dissolution of PuO_2. — Further dissolution tests were made with unirradiated PuO_2 reactor fuel pellets having a density of 10.3 g/cm^3, about 90% of theoretical density. The instantaneous dissolution rate of the pellets in boiling mixtures of nitric acid and hydrofluoric acid increased from 1.8×10^{-3} mg of PuO_2 per square centimeter per minute for 7 M HNO_3–0.005 M HF to 2.0 mg cm^{-2} min^{-1} for 14 M HNO_3–0.1 M HF. The instantaneous dissolution rate within this range of conditions is given by the equation $R = Q(\underline{M}\ HF)^{1.3}$, where Q is approximately proportional to the fourth power of the nitric acid concentration. The addition of 0.1 M $Na_2Cr_2O_7$ to the nitric acid did not affect the dissolution rate of the pellets.

Shear-Leach Process. — Engineering-scale development of the shear and leach process, which employs a 250-ton shear, a conveyor-feeder, and a rotary-drum leacher, was continued with unirradiated stainless-steel-clad UO_2 prototype fuel.

The four shear and leach runs made in order to investigate the buildup of uranium in the leacher led to the following conclusions: (1) At a dissolvent-to-fuel mole ratio of 4, the use of 7.5 M HNO_3 dissolvent resulted in the same uranium buildup rate as 7 M HNO_3 and produced a composite product which was unstable at room temperature. (2) At a mole ratio of 6, both 7 M HNO_3 and 8 M HNO_3 resulted in an initial 2- to 3-hr period of uranium inventory increase, followed by a period of uranium dissolution at a rate higher than the UO_2 addition rate. This suggests that there is no true steady-state condition but that long cyclic variations in uranium inventory are to be expected. (3) Under former operations, one sheared batch was added to the leacher per hour, and the addition of one-fourth of a batch of fuel at 1/4-hr intervals resulted in practically the same UO_2 buildup rate (about 1.5 g moles of UO_2 per hour) at an HNO_3/UO_2 mole ratio of 4. (4) The dissolution rate of UO_2 is significantly dependent on the

volumetric flow rate of the dissolvent, since the highest flow rate, 7 M HNO_3 at a mole ratio of 6, resulted in a higher dissolution rate than did either 7 and 7.5 M HNO_3 at a mole ratio of 4, or 8 M HNO_3 at a mole ratio of 6. Apparently, the higher dissolvent flow rate results in better mixing in the leacher flights, with a resultant higher dissolution rate.

Dissolution of 1-in. sheared lengths of stainless-steel-clad UO_2 in a bench-scale pot dissolver showed that a 50% increase in the volumetric flow rate of 7 M HNO_3 produced no increase in dissolution rate. The bench-scale pot thereby failed to reproduce the behavior of the rotary leacher, suggesting that the difference in configuration is an important one.

Hydrolysis of Uranium Carbides. — Basic chemical studies were continued on the hydrolysis of various uranium carbides in water. These studies were conducted with samples of uranium dicarbide that had a nominal composition $UC_{1.91}$, a combined C/U ratio of 1.88, and an apparent single-phase structure, as observed at 1000× magnification. When hydrolyzed in water at temperatures between 25 and 99°C, samples yielded 43 ml (STP) of gas per gram of carbide. The gas consisted of 48% hydrogen, 10% methane, 26% ethane, 5% C_3- to C_8-alkanes, 8% alkenes, 1% alkynes, and 2% unidentified hydrocarbon unsaturates. Of the total carbon in the sample, 33% was found in the gas phase and 32% as a water-insoluble wax. Temperature had no effect on the products of the reaction, which is in marked contrast to work by Litz, who reported 17% hydrogen at 83°C, compared with 47% at 100°C.

Chloride Volatility Process. — The use of various anhydrous gaseous chlorinating agents at elevated temperatures to convert U-Zr alloy fuels to the corresponding chlorides has been extended to other fuels as well. The latest studies include chlorination of U-Al alloy fuel, of plutonium, and additional work on U-Zr alloy fuel.

Changes in the procedure improved the "catalytic" chlorination of U-Al alloys, which is based on the formation and volatilization of aluminum monochloride by the reaction of aluminum trichloride with molten Al-U alloy. The aluminum monochloride formed at about 800°C decomposes in a relatively cool product-collection zone to form aluminum metal and aluminum trichloride, which is then available for further aluminum chlorination.

In a run made at 800°C and 15 mm Hg, with a 300°C temperature and a 1 mm Hg pressure at the cool end of the reaction tube, a 1-g rod of 5% U-Al alloy was 65% chlorinated in 6 hr. Efficiency in the use of aluminum trichloride, based on the weight of aluminum trichloride collected on the cool reaction tube exit, was 20%. No uranium was detectable in the volatilized fractions. A volatilization loss of 0.05% of the uranium could have been detected by the methods used.

The capacity of chlorine gas for the volatilization of plutonium as $PuCl_4$ was calculated from equilibrium constants recently determined by a transpiration technique (TID-14538) for the reaction $PuCl_3 + 0.5Cl_2 \rightleftharpoons PuCl_4$ to be 0.35, 1.55, and 2.94 mg of plutonium per liter at 500, 550, and 575°C respectively. This capacity, although small, is 17, 77, and 147 times as great, respectively, as required to volatilize all the plutonium during the chlorination of uranium oxide that has been irradiated to the 20,000-Mwd/ton level, assuming the use of a 50% excess of chlorine presaturated at room temperature with carbon tetrachloride vapor. Benz

(TID-14538) obtained excellent agreement in the measured equilibrium constants over a wide range of chlorine flow rates, showing that the kinetics of the reaction are rapid. This study indicates that recovery and decontamination of plutonium may be practical by the use of chloride volatility methods resembling those already demonstrated for uranium.

Two head-end processes for U-Zr alloy fuels were studied. The first involved the chlorination of the alloy at about 500°C with hydrogen chloride gas followed by adsorption of the products in aqueous solution; the second involved fuel chlorination at 170°C in hexachloropropene followed by extraction of the metal chlorides with water. In either process the chloride solution may be boiled down to 4 M $ZrOCl_2$–4 M HCl to produce a solution melting at 100°C and boiling at 110°C. The addition of a quantity of 50% H_2O_2 equal to 20% of the volume of the zirconium chloride solution removed over 70% of the chloride as chlorine. This step results in very little net volume change and reduces the melting point to below room temperature. The solution is then made 0.2 M in HNO_3 prior to solvent extraction.

Corrosion studies made under this subprogram indicate that the corrosion rate of nickel in chlorine at 500°C is less than 1 mil/month. In corrosion tests for the oxidation-chlorination process for graphite-UO_2 fuels, three specimens of Nichrome V corroded at rates of 8.6, 17.3, and 22.6 mils/month over 10 cycles consisting of 5 hr in oxygen at 800°C followed by 5 hr in Cl_2-CCl_4 at 500°C. No pitting or obvious local attack was noted.

Solvent Extraction. – The U-Zr alloy fuel solution prepared as described in the previous section was successfully extracted with tributyl phosphate. The solution of uranium containing 4 M Zr–0.1 M U–3 M Cl^-–0.2 M HNO_3 was contacted with equal volumes of 30% TBP in Amsco. Less than 0.001% of the zirconium and 84% of the uranium were extracted in the first run. In further extractions, zirconium was not detectable, and the percentage of uranium extracted decreased about sixfold per run. Four extractions were needed to remove 99.9% of the uranium.

In preparatory work for the BNL Kilorod operation, a laboratory countercurrent batch extraction experiment with 2.5% di-sec-butylphenyl phosphonate (DSBPP) in diethylbenzene (DEB), using only thorium as the salting agent, resulted in uranium decontamination factors of 500 and 1500 from gross gamma activity and thorium respectively. This process would produce an aqueous raffinate containing only thorium and nitric acid as macro components and would allow recycle within the system. Water was successfully used to strip uranium from the 2.5% DSBPP in DEB.

Protactinium Adsorption. – Studies on the adsorption of protactinium from thorium-uranium solutions on silica gel were continued. A new batch of silica gel was prepared; it had a surface area of 312 m^2/g, an ion exchange capacity of 0.07 meq OH^- per gram, and contained 0.16 wt % sodium. With this material, a protactinium adsorption distribution coefficient of 404 was obtained; 11% of the protactinium was unadsorbable. The previous batch of laboratory-prepared silica gel gave a coefficient of 575, with 13% of the protactinium being unadsorbable, and unfired Vycor gave a coefficient of 133, with 10% of the protactinium being unadsorbable. The adsorptions were made by contacting various amounts of 20- to 40-mesh adsorbent for 1 hr with a feed solution that was 11 M in HNO_3 and that

contained about 100 mg of thorium per milliliter, about 15 mg of uranium per milliliter, and 2.6×10^6 counts min^{-1} ml^{-1} of Pa^{233}.

Fluoride Volatility Pilot Plant. — The aqueous decontamination of the contaminated portions of the pilot plant was completed. Radiation levels at work areas in cell 1 are now generally less than 50 mr/hr.

During examination of equipment in cell 1, a crust of salt was found on the outside of the dissolver at the bottom, and it consisted of both process salt and residue from the aluminum nitrate used in the decontamination. Thermocouple failure data indicate that the leak probably developed during run R-1, the first in the series of six made with irradiated Zr-U alloy fuel. A 1-1/2-ft-high section at the bottom of the dissolver was removed for remote metallography, and a replacement section is being fabricated. The leakage was through two intersecting cracks — one horizontal and about 1-1/8 in. long between the lowest girth weld and the attachment welds for two stainless-steel-sheathed thermocouples, and the other a vertical crack about 3/8 in. long between the thermocouple welds.

After radiographs indicated undercutting in some fluorinator welds, two 4-in.-diam sections were cut out to facilitate examination of the vessel and its internal piping. The two sections removed include portions of four of the six welds in the bottom half of the fluorinator; they will be submitted for metallography.

Modifications of the plant are in progress. These include the removal of flanges between the fluorinator and the movable-bed absorber, the replacement of a flanged section of the condenser in the HF scrubbing system with a welded section, the installation of a solids cleanout device in the dissolver off-gas line, the installation of an MgF_2 bed to study technetium and neptunium removal, and revised piping to permit recycling of product UF_6 and improved operation of the movable-bed absorber.

Fluoride Volatility Processing. — Corrosion rates of various Ni-Fe-Mo experimental alloys were compared with those of INOR-8 and alloy 79-4 at Battelle Memorial Institute during exposure to HF for 200 hr in NaF-LiF-ZrF_4 (37.5-37.5-25 mole %) at 650°C without zirconium dissolution [see ORNL-3307, p 19, and ORNL-3368, p 11, for previous results of the use of NaF-LiF-BeF_2 (50.5-37-12.5 mole %)]. Metallography showed INOR-8 to be attacked the least, slightly more attack on alloy 79-4, with all the other experimental alloys being significantly worse.

Memorandum BMI-X-209 (Oct. 19, 1962) extended corrosion information obtained during conditions attempting to simulate the cyclic burning and fluorination of graphite-base fuels in nickel-base alloys (see ORNL-3368, p 12, for earlier results).

Each cycle consisted of a 1-hr exposure to 5% CO–65% CO_2–30% O_2 at 700°C and a 1-hr exposure to F_2 at 400°C, with 1-hr helium flushes during temperature transitions. Two such cycles were run each working day, with exposure to CO-CO_2-O_2 at 700°C overnight and to helium at room temperature on weekends. After 40 cycles, the maximum corrosion rates, according to metallography, were 6.5, 7, 9.5, 15, and 17.5 mils per month of total O_2 and F_2 exposure time for Duranickel (Ni, 4.5 wt % Al, 0.5 wt % Ti), L-nickel, INOR-8, Monel, and alloy 79-4 respectively. Only INOR-8 was free of intergranular attack.

THORIUM UTILIZATION PROGRAM

Planning and Evaluation Studies. — Evaluation of the Spectral Shift Control Reactor (SSCR) of Babcock and Wilcox and the High-Temperature Gas-Cooled Reactor (HTGR) of General Atomic was initiated. The reactivity lifetime of the SSCR was calculated by means of Equipoise Burnout, a two-group, two-dimensional fuel-depletion program. The fast-group cross sections were generated from the GAM-I spectral program. For the reference design, calculations were performed in which 10-day increments were employed, taking into consideration the change in the H_2O/D_2O ratio during fuel exposure. It was found that the reactivity lifetime at the terminal 2% D_2O content was 310 days; B&W obtained 350 days. A comparison of neutron balances indicated that there was reasonably good agreement between ORNL and B&W calculations except for the resonance absorptions in fuel cladding. ORNL used a resonance integral of about 2.2 barns for zirconium, whereas B&W used a value of about 0.17 barn. ORNL results gave an initial conversion ratio of 0.68; B&W obtained 0.75.

The present study of the Molten-Salt Converter Reactor (MSCR) was completed, except for the final report. The capital-cost estimate of the reactor and power cost systems by Sargent and Lundy was about $150/kw (electrical). Fuel cycle costs, on the basis of a central processing facility, were estimated to be about 0.7 mill/kwhr (electrical); the operation and maintenance costs were estimated to be about 0.3 mill/kwhr (electrical), by using the procedures described in the AEC Cost Evaluation Handbook.

Testing of Thoria-Pellet and -Suspension Fuels. — Samples of solids obtained during the running of in-pile slurry loop 0-1-28S have been analyzed for surface area by BET (nitrogen) techniques and for crystallite size by x-ray line broadening. The measurements indicate an increase in surface area from approximately 2 m^2/g to 24 m^2/g, in agreement with earlier measurements by another technique, and a decrease in crystallite size from greater than 2000 A to about 1000 A. A cumulative exposure of 7×10^{19} nvt and 2×10^{16} fissions/g was received by the solids.

The basic components of a third in-pile slurry loop, designated 0-1-29S, have been assembled. The general objectives of the experiment are to irradiate a suspension of pure ThO_2 in D_2O, for a substantial period of time at an elevated temperature, in order to assess the effects of extended irradiation and circulation on the properties of the slurry. Exposure time and intensity at a level comparable to that which would be received by ThO_2 in a reactor blanket are contemplated. The equipment, with the exception of an enlarged core, is similar to that of the previous in-pile experiment.

Engineering of Thorium Reactor Systems. — Experiments were carried out to measure the effect of thoria slurry on the pool boiling burnout heat flux of 1-1/2 × 1/4 × 0.005 in. test strips. The presence of concentrated slurry (1800 g of ThO_2 per liter), in addition to lowering the saturated burnout heat flux and reducing the effectiveness of subcooling below the predicted value, also restricts or prevents natural convection within the pool. At pool temperatures higher than 133°F (80°F subcooling), burnouts occurred frequently at fluxes at or close to the saturated burnout

flux, indicating that there was slurry at the boiling point surrounding the strip. At pool temperatures less than 130°F, this phenomenon did not occur.

Dilute slurry (850 to 950 g of ThO_2 per liter) reduced the saturated burnout heat flux and the effectiveness of subcooling slightly below the predicted amount. No low burnouts occurred, indicating that at this concentration the slurry did not affect the natural convection in the pool.

A high-temperature circulating slurry loop has been adopted so that forced-convection burnout heat fluxes can be measured at 250°C with high-concentration slurries. The strip will be 6 × 1/2 × 0.005 in. and will be located axially in a 1-1/2-in. pipe.

MOLTEN-SALT REACTOR PROGRAM

Molten-Salt Reactor Experiment. — Design work was completed on the drain-tank furnaces and heaters and the vapor-condensing system. Design is still in progress on the gas-handling systems and the electrical systems, but both are nearing completion.

Shop work was completed on the fuel flush tank. Assembly of the heat exchanger and radiator was started. A delay in schedule of the delivery of the graphite for the MSRE moderator from November to March will delay the completion of the reactor vessel. Work on other MSRE components is progressing as scheduled.

The outside construction work at Building 7503 was completed. The drain-tank cell and the reactor containment cell were completed and passed all leak and pressure tests.

The only work remaining on the major construction contracts is painting and minor cleanup.

Metallurgy. — A full-size heat exchanger mockup was made, to check assembly and fabrication techniques and to serve as a qualifying test for the MSRE heat exchanger brazing. In this unit, 52 tube-to-tube-sheet joints, 9 of which contained full-length tubes, were brazed with 82% Au–18% Ni alloys. The brazing was done in a hydrogen atmosphere at 1835 to 1885°F; however, temperature differences up to 400°F were measured during the heating cycle.

An evaluation of the heat exchanger joints by visual, ultrasonic, and metallographic techniques indicated that the brazing was successful. The unit was generally clean and bright, and full fillets existed. Ultrasonic inspection revealed no unbonded areas comparable to the 3/32-in.-diam standard, and a metallographic evaluation of those areas that caused some ultrasonic indications revealed only scattered porosity. Good braze flow and good bonding were also noted in the metallographic examination. Similar fabrication techniques will be used for the MSRE heat exchanger.

Chemical Development. — In connection with studies of the reaction of CF_4 with MSRE-type fuels, there was initially a general lack of success in attempts to provide melts in which a large fraction of the uranium was in the trivalent rather than the quadrivalent form. The inefficacy of metallic uranium as a reducing agent contrasted noticeably with the behavior in earlier fuel mixtures that did not contain BeF_2. Assuming the absence of

mechanical interference, this probably reflects the effect of the BeF_2-based solvent in giving a diminished stability of UF_3 with respect to UF_4 and uranium metal. Recently, MSRE-type melts that were "pretreated" with uranium metal were found to be readily reducible by further additions of zirconium metal. These melts, presumably in equilibrium with uranium metal at near unit activity, contain more than 0.5 mole % UF_3; on freezing, the trivalent uranium occurs as free UF_3. Such melts apparently react with CF_4 at 800°C at a measurable rate, but the rate decreases with time in a manner as yet incompletely explored.

Preparation of MSRE Materials. — To conform to recent revisions in the overall MSRE construction schedule, the production of purified fluoride mixtures for use as reactor fuel, flush, and coolant fluids has been tentatively rescheduled to begin in July 1963.

Cost estimates for beryllium fluoride have been received from two commercial vendors for quantities ranging from 5000 to 10,000 lb and for sulfur impurity levels from 250 to 1000 ppm. By deferring the procurement of this material, higher quality beryllium fluoride may be available in a more competitive market.

Sufficient lithium fluoride to provide for anticipated MSRE requirements for the next two years is being processed at the Y-12 Plant. Approximately 3000 lb of the 20,000-lb requirement has been prepared; the rest of the material will be available to the MSRE program by July 1963. The material produced thus far meets established chemical specifications except for the iron content. Quantities of 500 to 800 ppm of iron (50 ppm specification) have been reported by chemical analyses of several batches of material on hand. The introduction of this contamination has been attributed to impurities in hydrofluoric acid used in the process; further preparations have been discontinued pending receipt of acceptable hydrofluoric acid.

An experimental program to examine the operational variables of the fluoride purification process is in progress. Studies of the reduction rates of structural-metal impurities with hydrogen indicate a stronger dependence on gas sparging rates than previously contemplated. The use of higher sparging rates during fluoride production operations should reduce batch processing time and may permit structural-metal specifications (notably iron) for fluoride starting materials to be relaxed. Further efforts to develop the method of purifying molten fluorides with HF-H_2 mixtures are in progress. The results of these studies should also be applicable to the salt repurification process scheduled for installation in the MSRE facility.

Radiation Effects. — In irradiation experiment ORNL-MTR-47-5 the concentrations of CF_4 in helium cover gas over fissioning MSRE fuel containing submerged graphite were no greater than a detectable limit of 1 or 2 ppm; the gas samples that provided these favorable results were accumulated over periods as long as four days and were collected during exposure at power densities and temperatures that bracket MSRE conditions. The sampling system, which would not have revealed the presence of small amounts of fluorine at elevated temperatures, is being revised for future experiments. When the MSRE fuel froze during a scheduled shutdown, gas was evolved at a rate of several milliliters per day. Confirmation that this is another demonstration (cf. test 47-4) of the evolution of fluorine

by radiolysis in the solid state is being sought. Interestingly, the release of gas from the frozen fuel seems to occur only after an induction period.

Irradiation Tests. – The ORNL-MTR-47-5 MSRE capsule irradiation experiment has completed two MTR irradiation cycles. Twenty-seven gas samples have been collected to date. Operation was normal through the first cycle. During the first reactor shutdown, a pressure rise was noted in the isolated purge capsules. In capsule No. 4, which has 0.7 mole % UF_4, the pressure rise started almost immediately and continued throughout the shutdown at a slowly decreasing rate. In capsule No. 3, which has 0.35 mole % UF_4, there was a delay of 36 hr before the pressure rise was observable, after which it continued at a rate somewhat less than that of No. 4. The pressure rise during the 98-hr shutdown was equivalent to the generation of 8.1 and 23 std cc of gas in capsules 3 and 4 respectively. Capsule No. 3 was sampled once and No. 4 twice during the shutdown. Difficulty was encountered in removing these shutdown samples owing to the presence of long-lived moderately hard gamma radiation, not present in the gas samples taken while the reactor was in operation. As a consequence, gas sampling during the second cycle was curtailed. However, one 10-day sample was obtained from each capsule with the experiment fully retracted and one 30-hr sample was taken at the maximum power obtainable without exceeding 1500°F in any capsule. A 65-hr intermediate shutdown occurred in the second reactor cycle. During this period, the pressure in capsule No. 4 again began to rise but at a somewhat lower rate than had occurred during the previous shutdown. The pressure in capsule No. 3 did not rise measurably.

Analysis of Radioactive MSRE Fuels. – The following equipment has been assembled in the cell and partially checked out: an amperometric titration cell for the determination of zirconium, an automatic pipetter, a polarographic cell, and a filter photometer. The equipment for the determination of reducing normality was checked out and is being used routinely in HRLAF cells.

The prototype of transport-tube handling equipment is 60% complete. Other phases of the work necessary for analyzing the sample in the cell are approximately 50% complete.

Evaluation of the amperometric method for the determination of zirconium in the radioactive MSRE salt was continued. When the MSRE fluoride fuel is dissolved in sulfuric acid, the titration of zirconium can be performed without any prior separations. It is not necessary to remove fluoride ions; chloride does interfere, however. The precision of the method cannot be assessed accurately as yet. The precision on nonradioactive samples is 1%, which represents the ultimate precision that can be expected.

ADVANCED REACTOR DEVELOPMENT

Advanced Test Reactor Corrosion Program

Analysis of all the data regarding the effect of heat flux on the corrosion of aluminum by water shows that the corrosion product formed on

aluminum surfaces in proportion to about the 0.75 power of the exposure time. The 0.75 value appeared to be independent of heat flux, pH, alloy composition, and flow rate within the ranges investigated. The value of the proportionality constant was strongly dependent on the temperature at the specimen-water interface and the pH, and was somewhat dependent on the heat flux. Within the reproducibility of the results, the following empirical relationship describes reasonably well the oxide formation under the proposed operating conditions for both the ATR and the HFIR:

$$X = 1.2 \times 10^3 \ \theta^{3/4} \exp(-5000/K) ,$$

where X = oxide thickness in mils, θ = time in hours, and K = temperature at the specimen-water interface in degrees Kelvin. The above relationship is valid only at a coolant pH of 5 (with HNO_3), at flow rates of 35 to 45 fps, and at heat fluxes of approximately 1 to 2×10^6 Btu hr^{-1} ft^{-2}. At lower heat fluxes the above relationship predicts thickness values that are higher than those experimentally determined. Insufficient data are available to correlate the oxide formation rate with heat flux, pH, and flow rate.

High Flux Isotope Reactor Design and Development

Metallurgy. — Outer-annulus fuel plates containing dispersions of U_3O_8 in aluminum (rather than the U-Al alloy previously used) have been successfully fabricated. Both the fuel sections and filler pieces were prepared by hot-press forging. Core dimensions within the desired tolerances were obtained, and no blisters were found after a 500°C anneal.

It has been determined that the accuracy of wet chemical analysis for boron with the materials and the concentration levels found in the HFIR inserts is within only ±25%. Thus, without further development, the proposed homogeneity specification of ±15% is not practical. The reason for such a large variation is not known at this time.

A series of tests has been conducted to establish the feasibility of forming the fuel plates, using an electrohydraulic process. Encouraging results were obtained in forming the outer-annulus plates. The technique appears most useful when used for restriking plates rejected for not meeting dimensional tolerance after the low-pressure marforming. The maximum variation in curvature at any spot in 13 plates reformed by this method was only 8 mils, with the average spread being 4 mils.

A program has been initiated to develop procedures for manufacturing plates for the four-region control rods. The rods will consist of (1) a 26-in.-long, type 6061 aluminum "white" region, (2) a 7-in.-long "gray" region of 40 vol % Ta dispersed in aluminum, (3) a 20-in.-long "black" region of 40 vol % Eu_2O_3 dispersed in aluminum, and (4) a 12-in.-long "white" section of type 6061 aluminum. The rods are to be clad on both sides with 0.031 in. of type 6061 aluminum, resulting in a total thickness of 1/4 in. With the substitution of Lindsay mix for the europium oxide, a plate of the correct configuration, except for being one-third the required width, was successfully fabricated. Even with the necessary 30% cross rolling, the edges were straight and only minor end effects were

found. Neither blistering nor reactions between the many components were found after an anneal at 500°C. While the tantalum dispersion was sound, considerable cracking occurred in the europium dispersion. This is believed to be due to the high proportion of −325 mesh powder present in the original oxide.

At the request of the AEC, an exhibit on the HFIR fuel element was prepared; it was a major part of the AEC exhibit at the World Metals Congress in New York.

Design and Analysis. — In order to accommodate the desired design changes permitted by the increase in size of the pressure-vessel access hatch, and in order to take advantage of the improved method of vertical irradiation facility access and at the same time improve the cooling of the permanent reflector, a relocation of the vertical experimental facilities and coolant holes in the beryllium was undertaken. By permitting a maximum compressive thermal stress in the beryllium of about 24,000 psi (the limit on tensile stress is set at 12,000 psi) and by taking advantage of natural-convection cooling on the outer cylindrical surface, it was found that the bypassing of coolant holes around the engineering beam tubes in the beryllium can be eliminated.

Engineering Development. — The HFIR outer control plates are being studied to determine the magnitude of the loads and deflection caused by the thermal gradients and hydraulic loads imposed on a control plate during operation of the reactor at a 100-Mw power level. Experiments have been run to examine each of these conditions separately. The experimental data will be combined to give an indication of the deflection and load that will exist at several conditions of control-plate spacing and position. This will assist in establishing criteria for loads on control-plate skids and deflection-limiting roller bearings and will provide the designer of the control-plate safety system with criteria on the frictional forces to be overcome by the safety system.

The HFIR mockup is now being reassembled after having been dismantled for an inspection of the inner and outer control-rod drive system bearings located inside the mockup vessel. Several changes are required in order to develop bearings which are workable. Mockup parts are being altered to incorporate these changes.

Two additional pumps have been added to the mockup pumping system to bring the total number to six. This addition will permit operation of the mockup at flow rates up to 120% of design flow.

Instrumentation. — An analysis was performed on the analog computer to obtain more information regarding the performance and additional requirements of the HFIR safety and controls systems. The particular accidents studied were the startup accident, a step increase in δk at low power, a ramp increase in δk at high power, and various startup or failure modes of the main coolant pumps. The safety systems (level and rate) studied in this analysis do not appreciably affect the response of the reactor to low-power accidents which occur at 100% coolant flow. The close coupling between fuel and coolant and the reactivity effect of coolant heating provide self-shutdown protection which is not enhanced by the safety system. At 10% flow, self-shutdown is somewhat less effective, and the safety systems studied do provide a significant increase

in protection. At high power levels, protection is provided for ramp reactivity additions up to about 6.5% δk/sec.

It was determined that safety action is required to avoid hot-spot burnout upon loss of main coolant flow. The proposed flux-to-flow-ratio scram gives adequate protection.

Controller and rod action required to maintain control without a scram on reduction of main coolant flow due to loss of ac power was examined. Shim-rod assistance of approximately 2.5% negative δk in 15 sec is required under these conditions.

PHYSICAL RESEARCH PROGRAM

Reactor Operations. — During the first 45 weeks of 1962 the ORR was in operation 83% of the time. A contract has been let for 375 ORR fuel elements and 34 ORR shim rods.

The third annealing of the ORNL Graphite Reactor by reverse flow was completed on October 6. In preparation for this, the outer channels were partially blocked so that they received a smaller fraction of the coolant flow. This raised the temperature of the outer region to 140°C or greater in all but a few channels. Temperatures indicate that this anneal was much more complete than previous ones. Core samples of graphite are being taken to determine the extent of the release of stored energy from the graphite.

Waste Disposal. — The installation of monitoring equipment in the liquid-waste system and in the 3039 stack gaseous-waste disposal system was completed, although improvements and additions will continue to be made for some time. The Waste Control Center is now being manned continuously.

Trench No. 7 was put into service for the disposal of intermediate-level waste, and the use of open pits was discontinued. The pits will be filled and sealed as weather and the availability of manpower permit.

Hot-Cell Operations. — The hot cells continued in full operation. One meltdown of standard UO_2 and one of UC_2 embedded in graphite were disassembled and examined. Several ORR and LITR capsules containing UO_2 and UC_2 fuels were examined; included were two French capsules containing UO_2. Several irradiated molten-salt capsules were sampled for gas, and some were sectioned and sampled for various analyses and metallographic study. Two ORR poolside experiments were disassembled and specimens were recovered. A volatility pilot plant dissolver was sectioned and examination was begun.

PHYSICS AND MATHEMATICS RESEARCH

Charge Spectrometry. — With a specially designed mass spectrometer the relative abundances of the fragment ions resulting from the beta decay of CH_3Br^{82} were measured. Only $(0.43 \pm 0.09)\%$ of the observed ions are found as the parent ion, $(CH_3Kr^{82})^+$. However, in view of the large recoil energy present in the decay of Br^{82}, the binding energy of the C—Kr bond must not be negligible. Ten other ions are observed, of which the most abundant is CH_3^+. Recoil energy leads to the formation of CH_3^+, but the rest of the fragment spectrum is better explained in terms of excitation resulting from the nonadiabatic change in nuclear charge.

Neutron Diffraction. — Neutron scattering and magnetization measurements were made on dilute iron-palladium alloys to establish the existence and determine the magnitude of the magnetic moments of the constituent atoms. This determination was made by the combination of the difference in the aligned magnetic moments obtained from the ferromagnetic

diffuse neutron scattering and the average ferromagnetic moment per atom obtained from the saturation magnetization measurements. Data were taken on two alloys which contained 3 and 7 at. % iron. The following results were obtained:

$Pd_{0.97}Fe_{0.03}$	$Pd_{0.93}Fe_{0.07}$
$3.0 \pm 0.2\ \mu_B/Fe$	$3.0 \pm 0.2\ \mu_B/Fe$
$0.15 \pm 0.01\ \mu_B/Pd$	$0.27 \pm 0.02\ \mu_B/Pd$

Theoretical Physics. — A theoretical study was made of the scattering of neutrons, protons, and alpha particles from oriented target nuclei. In particular, calculations have been made for deformed nuclei, using the collective model, which has successfully accounted for inelastic scattering from these nuclei. Neutrons of 2, 5, and 14 Mev, protons of 5 and 14 Mev, and alpha particles of 43 Mev, incident on manganese and holmium nuclei were considered. The use of polarized targets is found to produce large changes in the elastic-scattering cross sections. When the nuclei are polarized perpendicular to the incident beam, the cross section for scattering in the "equatorial" plane is different from that for scattering in the plane containing the incident beam and the polarization direction; in particular, the sign of the difference is determined by the sign of the nuclear deformation. Measurement of this asymmetry will give a measure of the sign and magnitude of this deformation, as well as provide additional tests of the nuclear optical-model potential.

Fast-Chopper Time-of-Flight Spectrometer. — A large (9-in. diam × 12-in. long) sodium iodide crystal, with its associated shielding, was installed at a horizontal beam facility at the ORR. Gamma-ray spectra due to thermal neutron capture were obtained from isotopes of calcium and titanium exposed to the neutron beam. The spectra are dominated by strong gamma rays at 6.4 Mev in Ca^{40} (binding energy = 8.36 Mev), at 5.8 Mev in Ca^{42} (binding energy = 7.93 Mev), and at 5.5 Mev in Ca^{44} (binding energy = 7.42 Mev), involving transitions to excited states near 2 Mev. The same states show large reduced widths in the (d,p) reaction. It is reasonable to assume that these particular levels observed in Ca^{41}, Ca^{43}, and Ca^{45} consist of the target nucleus as a core and the odd neutron in the $2p_{3/2}$ orbital. Other weaker gamma rays in these calcium isotopes show this correspondence to transitions to levels observed to have $\ell_n = 1$ stripping patterns in the (d,p) reaction. Such a correspondence has received considerable attention in the analysis of thermal neutron capture. Similar results have been obtained for some isotopes of titanium.

Low-Temperature, Nuclear and Solid State Physics: Mössbauer Effect. — In the Mössbauer effect, there is a shift of the gamma-ray energy with the s-state charge density on the atom. In the noble-metal alloys the conduction electrons are in an s band. In an alloy, such as silver containing 1% gold, the additional resistance associated with the gold impurity is also associated with the charge state on gold. Thus one might anticipate a correlation between the residual resistance and the isomer

shift of the Mössbauer effect in these alloys. A study was made of the isomer shift of gold in alloys with copper and silver, and such a correlation was found.

Low-Temperature, Nuclear and Solid State Physics: Resonance Fission of Oriented U^{235} Nuclei. – Previous studies (Proc. Intern. Conf. Nucl. Struct., Kingston, Ont., 1960) of the angular distribution of fission fragments from thermal-neutron-induced fission of aligned U^{235} in the temperature region 77 to 1.3°K have been extended to 0.45°K and to the study of resonance-neutron-induced fission. Such angular distributions are primarily determined by the K quantum number values involved in passing over the barrier (see the citation above). The attainment of nuclear alignment at 0.45°K for the long periods of time required by low counting rates was accomplished with a continuously circulating He^3 refrigerator and the use of He^3 exchange gas to cool the single-crystal $UO_2Rb(NO_3)_3$ sample. Monochromatic neutrons were obtained from a beryllium crystal monochromator at the ORR. The results at 0.14 ev and for the 1.14- and 8.8-ev resonances yield A = 0.050 ± 0.002, 0.044 ± 0.006, and 0.051 ± 0.009, respectively, where A is the coefficient in $W(\theta) = 1 + (A/T)\ P_2(\cos\theta)$. The earlier "thermal" results and the results for the 0.28-ev resonance give A = 0.035 ± 0.005 and 0.031 ± 0.0015 respectively. The alpha-particle anisotropy, measured simultaneously and used as a monitor of the nuclear orientation, gave A = –0.070 ± 0.002, in accord with earlier work.

High-Voltage Experimental Program: Fission Cross Section and Fragment Angular Distribution for Fast-Neutron-Induced Fission of U^{234}. – The fission cross section of U^{234} has been remeasured to 4 Mev neutron energy with greater detail in order to accurately delineate the extrema. Results are believed to be somewhat more accurate than those previously reported. The fragment angular asymmetry, A, defined as the ratio of fragment emission at 0° to that at 90° to the neutron beam, was measured from 0.4 to 3.8 Mev. At 843, 1050, and 3740 kev the 30°/60° fragment-intensity ratio was also measured and normalized to A. Strong sidewise peaking with A = 0.50 (normal to the neutron beam) was found at 500 kev, at which point the total fission cross section is 0.50 barn and rising smoothly. At 843 kev the cross section passes through a maximum of 1.26 barns coincidentally with a maximum of 1.80 in A. From 843 to 1050 kev both cross section and A fall smoothly to minima of 1.10 barns and 1.13 respectively. Above 1050 kev both cross section and A rise somewhat irregularly. Between 1.5 and 3.8 Mev, A remains very nearly constant at 1.20.

High-Voltage Experimental Program: Differential Cross Section for Neutron Scattering from Pb^{208}. – Apparatus designed for determining neutron angular distributions with good energy resolution (Program of 1962 Meeting of the Southeastern Section of the American Physical Society, Abstract I3) has been used to measure differential cross sections for neutron scattering from Pb^{208} (99.75%) at a number of energies between 700 and 1750 kev. Collimated Li(p,n) neutrons were incident on the 128-g cylindrical sample in the center of a shielded region. The scattered neutrons were detected with a stilbene crystal from which gamma-ray pulses

were suppressed by use of pulse shape discrimination. For several prominent resonances below 1000 kev [Phys. Rev. 127, 2192 (1962)], the interference between the resonant and potential scattering (predominantly s-wave) allows one to assign ℓ values by inspection. This information together with published data (see the citation in the preceding sentence) gives the following resonance parameters (resonant energy in kev, J value, parity, and reduced width in units of $3h^2/2\ ma^2$): 723, 5/2, +, 0.02; 769, 3/2, −, 0.01; 821, 5/2, +, 0.04; and 855, 3/2, +, 0.02. As the neutron energy increases, potential scattering phase shifts other than s-wave become important, so that a more quantitative analysis is necessary.

CHEMISTRY RESEARCH

Effects of Radiation on Analytical Methods. — The effect of gamma irradiation on the thiocyanate—stannous chloride spectrophotometric method for molybdenum, including the radiation effect on thiocyanate under conditions prevailing during the extraction of the Mo-CNS complex, has been further investigated. The color of the Mo-CNS complex in butyl acetate extracts is essentially destroyed by doses greater than 1.5×10^4 r.

Studies were also initiated on the effect of gamma radiation on the thiocyanate spectrophotometric method for uranium. Uranium(VI) in aqueous solutions is stable to radiolysis. The color stability of the U-CNS complex, both in the presence and in the absence of $SnCl_2$, was investigated. In the absence of $SnCl_2$, the absorbance at 380 mμ increased with dosage; at doses greater than about 1×10^4 r, a suspension of elemental sulfur formed. In the presence of $SnCl_2$, absorbance decreased with increase in dosage until a dose of about 2×10^5 r was reached; at this level turbidity due to sulfur caused an increase in absorbance. Stannous chloride, therefore, appears to be a protective agent in the thiocyanate spectrophotometric determination of uranium; in its presence, errors due to irradiation tend to be negative and of lower absolute value.

Further studies were made of the effect of gamma radiation on various electrodes used in analytical chemistry. Subsequent tests indicate that previously reported data on electrode potential changes based on measurements initiated 5 min after irradiation of electrodes were in error and that ΔE values should be measured while the electrodes are being irradiated. Apparatus for this purpose has been constructed and tested. Further measurements will be made.

Solvent Extraction Research. — Preliminary tests showed that the process developed for solvent extraction recovery of fission product cesium with substituted phenols can be applied to the recovery of cesium from alkaline ore-leach solutions. Solutions of alkali-metal carbonates (by-products of the lithium industry) and solutions produced by the alkaline fusion of pollucite were studied. More than 99% of the cesium was recovered and separated efficiently from contaminants, including other alkali metals, by extraction with a 1 M solution of 4-sec-butyl-2-(α-methylbenzyl)phenol in diisopropylbenzene and stripping with nitric acid. By adjustment of conditions, rubidium can also be extracted and separated from the other alkali metals.

The stability of nearly pure meta and para isomers of diethylbenzene toward boiling 2 M HNO_3 was evaluated in further testing of alkylbenzenes as diluents for processes using organophosphorus extractants. In a test in which degraded 1 M TBP-Amsco 125-82 extracted 4000 counts/sec of Zr-Nb^{95} from 2 M HNO_3, similarly degraded 1 M TBP solutions in m- and p-diethylbenzenes extracted 100 and 6000 counts/sec respectively. Infrared absorption tests showed that of five commercial diethylbenzenes tested, the most stable had the lowest para-isomer content.

Process Chemistry of Uranium and Thorium. — Three drill cores to depths of 500 to 600 ft, obtained from the Conway granite formations in New Hampshire, showed no significant variation in thorium content or thorium leachability with depth. On the basis of this and previous information, thorium reserves in the top 600 ft of the Conway granite have been estimated at 20 million tons.

Volatility Studies. — The reprocessing of Al-U alloy reactor fuel by the fused-salt-volatility method appears feasible on the basis of initial dissolution studies. Aluminum dissolution rates of 12.3, 6.0, 2.4, and 1.7 mils/hr were obtained in hydrofluorination tests at 600°C, using KF-ZrF_4 (67-33 mole %) at AlF_3 concentrations of 5, 15, 25, and 35 mole % respectively. An increase in viscosity possibly accounts for the marked decrease in dissolution rates at the higher AlF_3 concentrations.

Decontamination studies were made for nickel equipment that had been exposed to molten processing salt for several hundred hours. The most effective method consists in treating the metal first with a slightly corrosive solution to remove 1 to 2 mils, then with a complexing solution to remove back-adsorbed material from the surface. A 0.1 M $Al(NO_3)_3$ solution used at 90 to 100°C is suitable for the first treatment, and a solution consisting of 2 to 5% NaOH, 2 to 5% sodium tartrate, and 1 to 2% H_2O_2, used at ambient temperature, is recommended for the second.

Physical Chemistry of Ion Exchangers. — Heat of solution and dilution measurements were completed on p-ethylbenzene sulfonic acid (the "model" compound for strong-acid, cation exchangers) and on the lithium, sodium, potassium, and cesium salts of the acid for concentrations in water from near saturation down to about 0.05 m. Apparent molal heat contents, ϕ_L, relative to infinite dilution were derived and plotted as a function of concentration to facilitate the estimation of the heat content differences, $\Delta\phi_L$, between the various salt solutions. If cation exchange resins may be considered analogous to concentrated electrolyte solutions, the standard heat of an ion exchange reaction should be approximated by the $\Delta\phi_L$ for the two p-ethylbenzene sulfonates, M_1R and M_2R, at concentrations corresponding to the concentrations of cations M_1^+ and M_2^+ in the ion exchanger. The $\Delta\phi_L$ values thus computed were in reasonably good agreement with the standard heats for the exchange of sodium ion with hydrogen, lithium, or cesium ions in Dowex-50-type exchangers of nominal 2, 4, and 8% divinylbenzene cross-linking. Poor agreement was found for the exchange with potassium ion, however. It seems unlikely that the heat of dilution or heat of exchange measurements were in error. Possibly the equivalent water contents of the potassium resinates were incorrect, or possibly potassium ion is actually different from the other alkali-metal cations in concentrated aqueous polyelectrolyte solutions.

High-Temperature Aqueous Solution Chemistry: Liquid-Liquid Immiscibility and Critical Phenomena in the Condensed System UO_3-CuO-NiO-SO_3-D_2O, 270 to 410°C. – The investigations of liquid-liquid immiscibility and critical phenomena in the condensed system UO_3-CuO-NiO-SO_3-D_2O were essentially completed. These studies, carried out between 270 and 410°C, defined temperature limits over which a second liquid phase saturated the solution or at which critical phenomena were observed, for compositions with SO_3 concentration varying from 0.05 to 1.0 m, with molal ratio (total metallic oxides):SO_3 varying from 0.10 to 1.0, and with molal ratios UO_3:CuO:NiO of 8:1:1, 4:1:1, 2:1:1, and 1:1:1. In the two-liquid phase regions, as an approximation, CuO, NiO, or both can be stoichiometrically substituted for UO_3 in small amounts in a particular composition without changing appreciably the temperature of liquid-liquid immiscibility from that of the system UO_3-SO_3-H_2O ("Liquid-Liquid Immiscibility and Critical Phenomena in the Systems UO_3-SO_3-H_2O, UO_3-SO_3-D_2O, and CuO-SO_3-D_2O, 270–430°C," J. Inorg. Nucl. Chem., in press).

High-Temperature Aqueous Solution Chemistry: The System Li_2SO_4-H_2SO_4-H_2O and Its D_2O Analog, 200 to 400°C. Solubilities and Critical Phenomena. – The solubilities of Li_2SO_4 in H_2SO_4-H_2O and in D_2SO_4-H_2O solutions in equilibrium with vapor were determined at temperatures between 200° and 350°C and at concentrations of free acid from 0 to 1.5 m. Solubilities in H_2O media at 200° varied from 2.7 m in H_2O to 2.79 m in 0.83 m H_2SO_4, and at 350° varied from 0.1183 m in H_2O to 2.38 m in 1.46 m H_2SO_4. Corresponding solubilities in D_2O media were from 10 to 40% lower. The solubilities of stoichiometric Li_2SO_4 in H_2O were in good agreement with those published recently [Zhur. Neorgan. Khim 6, 2380 (1961)]. Temperatures of critical phenomena (where liquid is identical with vapor) varying between 374 and 470°C were determined visually for solutions of Li_2SO_4, D_2SO_4, and D_2O at concentrations of SO_3 from 0.02 to 2.5 m and at molal ratios, Li_2O:SO_3, varying from 0 to approximately 0.5.

High-Temperature Aqueous Solution Chemistry: Hydrates of UO_3 in the System UO_3-N_2O_5-H_2O. – The stable UO_3 hydrates which saturate HNO_3-H_2O solutions at temperatures between 25 and 325°C were identified by comparison of their x-ray diffraction patterns with those established previously (J. Chem. Soc. 1956, 3531). At each temperature studied, seven solutions, varying in HNO_3 concentration from 0 to 1.5 m, were saturated with solid, initially α-$UO_3 \cdot H_2O$. Over the entire range of concentration, α-$UO_3 \cdot H_2O$ was identified as the stable saturating solid at 25, 135, 170, and 200°C. The saturating solid phase was β-$UO_3 \cdot H_2O$ at 235 and 270°C, and $UO_3 \cdot 1/2H_2O$ at 300 and 325°C. These temperatures of stability for the various hydrates are in agreement with those found previously in the system UO_3-SO_3-H_2O [J. Inorg. Nucl. Chem. 22, 115 (1961)].

Physical Chemistry of Gaseous Mixtures. – The effects of various parameters on the transport properties of dissociating gaseous mixtures were studied. Estimates were made of thermal conductivity, specific heat, viscosity, and specific volume of helium–aluminum chloride and helium-fluorine mixtures as a function of temperature at various pressures and compositions. The maxima in the thermal-conductivity and specific-heat curves, which are due to the heat of dissociation, can be varied over a

wide range of temperature by controlling the pressure and the helium concentration. The dissociation reaction produces a greater-than-linear increase in specific volume with increasing temperature. According to these calculations, the thermal conductivity and specific heat of a helium-fluorine mixture can be as much as twice the corresponding values for pure helium, while the viscosity of the mixture is approximately 10% greater than that of helium and is only slightly dependent on composition. The thermal properties and viscosity of helium-aluminum chloride mixtures are considerably less than those of pure helium.

Chemical Separation of Isotopes. — A Raman spectrum of XeF_2 prepared by D. F. Smith (ORGDP) was recorded. The following lines were measured:

Raman Frequency (cm^{-1})	Relative Intensity
108	32
497	100
548	7.3

A single-stage separation factor of 1.00017 ± 0.00007 per mass unit was measured between RbOH and Rb amalgam. The heavy isotope enriched in the amalgam phase. The separation factor $(Rb/Cs)_{aqueous}/(Rb/Cs)_{amalgam}$ was in the range 2 to 3, depending on temperature and concentration.

Chemical Applications of Nuclear Explosions. — Laboratory work on sulfate reductions by hydrogen was extended to include strontium and barium sulfates in order to further verify the hypothesis that sulfites are intermediates in sulfate reductions. Partial reductions of equimolar samples of $MgSO_4$, $CaSO_4$, $SrSO_4$, and $BaSO_4$ produced direct evidence that in each case the corresponding sulfite is an intermediate: sulfite was shown to be present in the solid reduction product. The observed order of the quantity of sulfite in the solid product was $BaSO_4 > SrSO_4 > CaSO_4 > MgSO_4$; this is the same as the order of thermal stability of the sulfites. The order of the amounts of SO_2 in the off-gas was $MgSO_4 > CaSO_4 > SrSO_4 > BaSO_4$, which is again consistent with the known thermal stabilities of the sulfites.

The mechanism of sulfate reduction by hydrogen thus appears to be the reduction of sulfate to sulfite, with subsequent thermal decomposition of the sulfite and reaction of the reducing gas with the sulfite decomposition products. By this mechanism, the products of a given sulfate reduction can be predicted readily from the thermal decomposition data of the corresponding sulfite.

METALLURGY AND MATERIALS RESEARCH

Ceramics Research: Sintering Studies. — The presence of a maximum and a minimum in the curve of densification rate vs temperature for ThO_2 powder compacts being heated at a uniform rate has been reported (ORNL-3279, p 22). Further investigation has indicated that the presence of

impurity ions causes this densification rate variation. Preparation of a specimen from the purest ThO_2 available resulted in a densification rate curve without a minimum. The position of the minimum was shifted slightly by the addition of small quantities of impurities. Apparently, the impurity ions impede the motion of dislocations, with resultant restriction of the densification rate. The impurity-ion influence varies with temperature, causing the extent of restriction of dislocation movement to vary with temperature. The variation of impurity impedance of dislocation motion with temperature appears also to be the cause of a minimum in the curve of densification rate vs temperature for sodium chloride powder compacts. There is a qualitative agreement between the NaCl densification rate minimum and a maximum in the yield stress of NaCl found by Eshelby et al.

CONTROLLED THERMONUCLEAR RESEARCH

DCX-1 Facility. – The repair of leaks in an O-ring seal joining two large structural components required disassembling a major portion of the vacuum tank. This opportunity was taken for a complete disassembly and cleaning of the entire vacuum system. The apparatus is now reassembled and operating, and determinations of the H_2^+ beam orbits under various injection conditions are in progress.

High-Current Injection. – The original accelerator tube developed for high-current injection was replaced on the DCX-2 with one having epoxy skirts cast around the porcelain insulators. Two of the insulators had developed conductive paths along their exterior surfaces which could not be easily removed. The new tube has operated up to 640 kv. There are still some involuntary shutdowns initiated by either internal or external discharges. The problem of achieving a more desirable level of stability is continually being pursued.

An FM link was developed to transmit current information with a time resolution of about 10 μsec from the 600-kv level to ground. This current cannot be measured in the ground leg of the supply, because of the large ac ground currents associated with the nature of the supply itself.

Theory. – Following recent experiments, a study has begun of the stabilizing effect of an electron beam passing through the DCX plasma. It has been conjectured that the Harris instability arising from ion-electron interaction could be controlled by this means if $V_g/L > \gamma$, where V_g is the group velocity of waves, L is the plasma dimension, and γ is the instability growth constant. Then random electric field energy which might excite the instability flows away harmlessly down the beam before growth at the expense of plasma kinetic energy can occur. A preliminary calculation of the group velocity for a system of a monoenergetic ion beam in a uniform magnetic field with monoenergetic electrons streaming through suggests that electron beams of a few hundred volts energy should produce an effect.

Radio-Frequency Heating. — Since the last report on radio-frequency heating (ORNL-3331, p 27), an intensive effort has been under way to obtain an energy spectrum of the neutrons emanating from the "electron cyclotron" plasma in the Physics Test Facility. The low neutron production rate and high gamma-ray flux combine to make the problem extremely difficult. Four different methods of obtaining the neutron energies have been attempted. These are activation of S^{32}, counting of recoil proton tracks in nuclear emulsions, use of high-pressure He^3 proportional counters, and use of the Bonner hydrogenous sphere spectrometer [Nucl. Instr. Methods 9, 1 (1960)].

Although the data are rather crude at present, they are all consistent with the interpretation that most of the neutrons have kilovolt energies, with only about 10% having Mev energies. A process which can produce neutrons with kilovolt energies is electrodissociation of deuterons by electrons. The cross section for this reaction has a threshold at 2.2 Mev and rises to about 10^{-6} barn at 2.7 Mev. From an estimated deuteron density of $10^{12}/cm^3$ and the above reaction cross section, one may calculate the density of 2.2-Mev electrons required to produce the observed kilovolt neutron flux. This is 10^9 electrons/cm^3. Plasma x-ray spectra indicate that this density of electrons may be present when microwave power is ~2 kw.

A 4-mm microwave interferometer has been used to measure plasma electron density. The measured phase shift at full microwave power corresponds to a density of $\sim 2 \times 10^{11}/cm^3$, which is an order of magnitude lower than the density indicated by neutral-beam measurements. Calculations show that the index of refraction for a magnetically confined electron plasma can approach 1 when the Larmor orbit circumference becomes as large as the wavelength of the applied radiation. With 4-mm radiation this condition is satisfied by electrons above 5 kev. X rays from the plasma suggest that many of the electrons are above this energy. These electrons are still efficient ionizers, and therefore interact with the molecular beam, though not with the 4-mm microwaves.

In order to study the scaling properties of the electron cyclotron plasma, an experiment is being planned with a plasma volume of ~150 liters. This will require a proportional increase of microwave power to ~30 kw. Delivery of three 10-kw klystrons for 10.4 kMc is expected in about four months.

BIOLOGY AND MEDICINE PROGRAM

RADIATION EFFECTS

Pathology and Physiology. — Radioprotective chemicals [such as S,2-aminoethylisothiourea (AET)] and isologous bone marrow (IBM) have each been used successfully to alter the course of the acute radiation syndrome. In the present experiments, animals surviving acute doses of radiation with such treatment have been followed until death to note changes in life span, disease incidence, graying of fur, and cataract formation. Young adult female (101/Cum × C3H/Anf Cum)F_1 mice were exposed

to 350–1800 r of 250-kvp whole-body x rays. Some of the exposure groups were treated immediately prior to irradiation with 8.8 mg of AET per mouse, while others received 10×10^6 isologous femoral bone-marrow cells after irradiation; additional groups received both treatments. Selected mice were checked periodically for graying of fur and lens opacities, and an autopsy was performed on each mouse. Radiation shortened the life span in all groups, but the degree of life-shortening per roentgen was less at the higher dose levels, especially in mice given AET and/or IBM; that is, the mean survival time of the heavily irradiated, treated groups (1100 to 1800 r) was only a little shorter than that of the LD_{50} radiation controls (700 to 800 r). The incidence of neoplasms was lower in heavily irradiated, IBM- or AET-treated animals than in mice given smaller doses of radiation with or without protective treatment. However, tumors of the ovary were numerous after radiation, and neither AET nor IBM appeared to protect against their induction. The incidence of thymic lymphoma was increased by radiation, and its induction was inhibited by either AET or IBM treatment. Graying of fur in irradiated mice was reduced by pretreatment with AET. Late kidney damage (glomerulosclerosis) was common in survivors of heavy radiation doses and was not consistently reduced by AET or IBM treatment. The induction of lens opacities was not altered by AET or IBM. The lesser life-shortening effectiveness of radiation in the most heavily irradiated, treated mice probably can be ascribed to protection by AET or IBM, although there was absence of similar protective effects at lower dose levels. Final interpretation of the long-term protection afforded by AET and IBM will, therefore, require further analysis of dose-response relations, as influenced by intercurrent mortality from specific radiation-induced diseases.

Recovery from Somatic Effects of Radiation. – The competence of bone marrow to promote recovery of hemopoietic and immunological function in irradiated recipients has been observed to vary upon serial transplantation. It was the purpose of this study to investigate the nature and cellular basis of such variations. To obtain a quantitative measure of the proliferative capacity of the transplanted marrow cells, their ability to form hemopoietic colonies and to promote the uptake of I^{131}-labeled iododeoxyuridine (UDR) in the recipient spleen was determined. The proliferative capacity was also related to the cellular constitution of the donor marrow by means of differential cytologic analysis. Observations were carried out in $(BALB/c \times A/He)F_1$ mice subjected to 850 r of whole-body 300-kvp x irradiation followed immediately by intravenous injection of 10^7 nucleated isologous bone marrow cells. Such mice were killed at 5-day intervals up to 40 days after transplantation, and their marrow was retransplanted for the assay into isologous recipients exposed to 700 r of whole-body 300-kvp x irradiation.

When bone marrow was retransplanted within 15 days, its ability to colonize the recipient spleen and to give rise to DNA-synthesizing cells (as judged by uptake of I^{131}-UDR) was poor, although myeloblasts and erythroblasts were relatively abundant in the donor marrows. The normal repopulating capacity of the marrow returned 30 or more days after transplantation and was correlated with the reappearance in the marrow of normal numbers of lymphocyte-like cells. These results indicate that the

capacity of the marrow to repopulate hemopoietic sites in irradiated recipients is not dependent on its content of erythroblasts and myeloblasts but rather on its content of more primitive precursors. The results suggest, furthermore, that the stem cell may be related morphologically to the small lymphocyte.

Physiology of Blood Platelets. — Labeling of blood platelets of rats in vivo by injection of $Na_2S^{35}O_4$ was found to increase to a peak at 3 days after a single intravenous injection. Chemical analysis revealed that at least 50% of the S^{35} activity in platelets 48 hr after S^{35}-sulfate injection was present in a sulfated mucopolysaccharide (MPS). The observation that radioactivity of whole-saline-washed platelets appeared to be higher at 6 than at 12 hr raised the question, however, whether platelets are labeled with S^{35}-sulfate by two different mechanisms. The experiments reported here demonstrated first that whole-platelet radioactivity is indeed high 1 hr after sulfate injection, declines rapidly to a low value between 12 and 16 hr, and then rises again as observed previously. Chemical analysis of the platelets at intervals from 1 to 32 hr after sulfate injection revealed that no S^{35}-labeled MPS could be detected in platelets at 1, 4, and 8 hr, but that MPS-S^{35} increased thereafter. It thus appears that platelets in the peripheral circulation are labeled immediately after sulfate injection, possibly by adsorption, and that this kind of labeling rapidly decreases with the decline in platelet radioactivity. Several hours after sulfate injection, platelets containing MPS-S^{35} begin to appear in the blood. The latter kind of labeling takes place in the bone marrow while the platelets are still part of the cytoplasm of the megakaryocytes, their progenitors. Release of platelets labeled in this manner into the circulation is a function of the maturation of labeled megakaryocytes rather than of the level of radioactivity in the circulating blood.

Medium(Low)-Level Long-Term Effects of Radiation. — Since a growing number of viruses have been implicated in the pathogenesis of spontaneous and radiation-induced murine tumors, the metabolic effects of viruses on host cells, as influenced by irradiation, are being investigated in an effort to determine the mechanism of virus-induced neoplastic transformation. The present experiments were undertaken to analyze the RNA of P^{32}-labeled HeLa S3 cell cultures infected with Coxsackie B3 virus. Three-day cultures of HeLa S3 cells were overlaid with 35 ml of medium 199 containing 2.0 mc of P^{32}. The test cultures were infected with Coxsackie B3 virus at a multiplicity > 2.0 one hour after addition of the P^{32} medium. Both uninfected control cultures and infected test cultures were harvested 5 hr after addition of P^{32}. Three fractions of RNA were isolated from phenol extracts of the harvested cultures: an aqueous RNA, an interface RNA, and RNA associated with the DNA that was concomitantly extracted. The distribution of isotope among the bases of these three RNA fractions was determined. Preliminary analyses of the patterns or "fingerprints" of these various RNA fractions have been made by two-dimensional chromatography of pancreatic ribonuclease digests of each of the three fractions from both control and virus-infected cultures. The aqueous and interface

RNA of uninfected cells exhibited similar isotope distributions among their bases, and the isotope distribution among the bases of both of these fractions was similarly altered upon Coxsackie B3 virus infection. The DNA-associated RNA revealed an isotope distribution among its bases markedly different from that of aqueous and interface RNA, and the distribution was not altered upon Coxsackie B3 virus infection. Preliminary results of the RNA fingerprints indicated some differences both between the three individual RNA fractions and between control and virus-infected samples of the same fraction.

COMBATING DETRIMENTAL EFFECTS OF RADIATION

Mammalian Recovery. – The recent finding that stem cells, capable of repopulating hemopoietic and lymphopoietic tissues of irradiated mice, occur normally in the peripheral blood suggested the possibility of finding such cells also among peritoneal fluid cells (PFC). Cells harvested from peritoneal cavities of normal F_1 hybrid mice, either stimulated or not, were injected into lethally irradiated mice of an inbred strain. The capacity of PFC to differentiate and proliferate was evaluated by several criteria, including survival of chimeras; Fe^{59} uptake; microscopic appearance of stained, fixed tissues; and serological identification of erythrocytes and nucleated hemopoietic cells. PFC were shown to give rise to permanent, apparently normal hemopoietic and lymphatic systems. Efficiency of PFC is far smaller than that of bone marrow cells and appears to be like that of white cells from circulating blood of the normal mouse.

Radiation Immunology. – Studies on the growth of mouse spleen cells capable of differentiating into antibody-forming cells revealed that a 100-fold increase takes place between 2 and 40 weeks after birth. During this period the body weight, spleen weight, and number of cells per spleen increased only tenfold or less. Cells capable of responding to a homograft appeared much earlier; this would suggest that a repressor mechanism is preventing expression of the structural gene site for antibody synthesis.

Further studies on the fate of spleen cells from nonprimed and primed donors when transferred into lethally irradiated, genetically compatible recipients indicate that a distinct difference exists. In the former case the pool size of cells capable of differentiating into antibody-forming cells when stimulated with a test antigen decreases fourfold within a week after transfer, before it levels off. This decrease can be partially prevented by transferring bone marrow cells together with the spleen cells. In the latter case the pool size remains constant. These findings do not support the classical clonal theory but do support the interpretation that there exist in the spleen of a nonprimed animal multipotent cells capable of differentiating along two or more paths.

In order to make a quantitative study of the role of the graft tissues in the splenomegaly response of chick embryos, varying concentrations of spleen cells were introduced intravenously, and the spleen enlargement was estimated by wet weights. With this approach a series of comparable

experiments were conducted to determine the relation between splenic enlargement and (1) cell dose, (2) origin of spleen cells (homologous or heterologous), (3) age of host embryo, and (4) irradiation effect of host embryo. Preliminary results generally confirm the previous work of the group and provide further information on the quantitative response as a function of injected cell dose, source of spleen cells, age of host embryo, and effect of irradiation on the responding system.

MOLECULAR- AND CELLULAR-LEVEL STUDIES

Cell Growth and Reproduction. — It is well established that the yolk platelets in an amphibian egg constitute a main reservoir which is utilized during ontogeny as a source of building materials, of energy, or of both. The present electron microscopic studies show a close relation of yolk platelet utilization and progressive differentiation of cells. The yolk platelets of amphibian egg contain a superficial layer of threadlike materials (20 to 100 A), a central main body of crystalline lattice structure, and an enclosing membrane approximately 70 A thick. The first change in the yolk platelets is visible in a decrease in thickness and a subsequent disappearance of the superficial layer in cells undergoing primary differentiation. At later stages the surface of the crystalline structure decomposes into separate units 40 A in diameter. Further disintegration of the main body is coupled with the formation of laminated membranes, multivesicles, microparticles, and microfibrils. The ultrastructure of the membranous components is very similar to that of cytomembranes. It is not improbable that these membranes represent an intermediate step in the formation of cytomembranes, which are known to increase in amount during the corresponding phase of cell differentiation. When the decomposition of yolk platelets occurs, mitochondria, pigment granules, and lipoid bodies are found in a close association with the yolk platelets. In *Rana* species (as opposed to other amphibian species), crystalline structures typical of yolk platelets are frequently located within the mitochondria throughout embryonic development. Further analysis is needed to determine whether the remarkable picture indicates a transformation of yolk platelets into mitochondria, uptake of yolk platelets into mitochondria, or an abortive formation of yolk crystal within mitochondria.

Biophysics: Considerations of Variation of Biological Radiosensitivity with LET. — Different basic mechanisms may produce the same observed biological effect. Although for health physics, consideration of the overall effect may suffice, for radiobiology a study of a single mechanism at a time is desirable. One differentiation of mechanisms is separation of different powers of dose dependence. The effect produced by mechanisms going by dose response D^n is

$$E_n = D^n \int_0^\infty R_n(L)\phi(L)\, dL = \overline{R}_n[\phi(L)]D^n ,$$

where $R_n(L)$, the function really desired, is proportional to biological sensitivity for dose given at spatial rate L; $\phi(L)\ dL$ is the fraction of total absorbed dose given in interval L to L + dL; and $\overline{R}_n[\phi(L)]$ is the observed coefficient. To graphically present variation of sensitivity with linear energy transfer, one needs the biophysical average $\overline{L}$ such that

$$R_n(\overline{L}) = \overline{R}_n[\phi(L)] = \int_0^\infty R_n(L)\phi(L)\ dL\ ,$$

where $R_n(\overline{L})$ is the same function as $R_n(L)$. One then takes $R_n(L) = \alpha + \beta f(L)$, and for assumed functions f(L) computes $\overline{L}$ from the integral, attempting to find f(L) such that a plot of $\overline{R}_n$ vs $\overline{L}_n$ reproduces the shape of the assumed $R_n(L)$. For the Tradescantia data [Radiation Res. 9, 525 (1958)], preliminary evaluation suggests $R_n(L) = 0 + \beta L e^{-\gamma L}$.

Biophysics: Vacuum Ultraviolet Irradiation of Cells. – Work was completed on the photoreactivation of conidia of Streptomyces griseus after exposure to vacuum ultraviolet radiation. The conidia were dried on the surface of millipore filters and exposed to the vacuum of the source, an experimental, magnetically constrained dc carbon arc, operated with a low pressure of argon. The photoreactivable sector (fraction of radiation damage that can be reversed) dropped steadily from the region of 2300 A to zero at 1548 A. Throughout this range, the photoreactivation rate remained constant. Although the precision of the data increases with wavelength, being perhaps ±20% at 1548 A, the following conclusions are nevertheless strongly supported: (1) photoreactivation does not occur for inactivation by all nonionizing radiations below 3000 A; (2) photoreactivation applies only to damage resulting from excitation in the electronic band that peaks at 2600 A, a conclusion consistent with its operating only on thymine dimers.

RADIOLOGICAL PHYSICS, HEALTH PHYSICS, AND INSTRUMENTATION

Basic Instrumentation. – Guard-ring-type silicon surface barriers were successfully operated at liquid-nitrogen temperature. For Cs^{137} conversion electrons the best resolution with a 20-mm^2 device was 5 kev (full width at half maximum).

OPEN LITERATURE PUBLICATIONS

Anderson, N. G., "Analytical Techniques for Cell Fractions. II. A Spectrophotometric Column Monitoring System," Anal. Biochem. 4, 269 (1962).

Anderson, N. G., "The Zonal Ultracentrifuge: A New Instrument for Fractionating Mixtures of Particles," J. Phys. Chem. 66, 1984 (1962).

Baes, C. F., Jr., "An Isopiestic Investigation of Di-(2-ethylhexyl)-phosphoric Acid (DPA) and Tri-n-octylphosphine Oxide (TPO) in n-Octane," J. Phys. Chem. 66, 1629 (1962).

Bair, J. K., and H. B. Willard, "Level Structure in Ne^{22} and Si^{30} from the Reactions $O^{18}(\alpha,n)Ne^{21}$ and $Mg^{26}(\alpha,n)Si^{29}$," Phys. Rev. 128, 299 (1962).

Bender, M. A, and D. M. Prescott, "DNA Synthesis and Mitosis in Cultures of Human Peripheral Leukocytes," Exptl. Cell Res. 27, 221 (1962).

Bienlein, J. K., and Frances Pleasonton, "The Half-Life of He^6," Nucl. Phys. 37, 529 (1962).

Bond, H. E., "A Sex-Associated Protein in Liver Tissue of the Rat and Its Response to Endocrine Manipulation," Nature 196, 242 (1962).

Carroll, R. M., "Fission-Product Release from UO_2," Nucl. Safety 4, 35 (1962).

Clayton, R. K., "Evidence for the Photochemical Reduction on Coenzyme Q in Chromatophores of Photosynthetic Bacteria," Biochem. Biophys. Res. Communs. 9, 49 (1962).

Clayton, R. K., "Primary Reactions in Bacterial Photosynthesis. I. The Nature of Light-Induced Absorbancy Changes in Chromatophores; Evidence for a Special Bacteriochlorophyll Component," Photochem. Photobiol. 1, 201 (1962).

Collins, C. J., M. M. Staum, and B. M. Benjamin, "Molecular Rearrangements. XX. The Deamination of erythro- and threo-1-Amino-1-phenyl-2-p-methoxyphenyl-2-propanol and erythro- and threo-1-Amino-1-phenyl-2-o-tolyl-2-propanol," J. Org. Chem. 27, 3525 (1962).

deSerres, F. J., and Rosalie S. Osterbind, "Estimation of the Relative Frequencies of X-Ray-Induced Viable and Recessive Lethal Mutations in the ad-3 Region of Neurospora crassa," Genetics 47, 793 (1962).

Doria, Gino, "Homograft Reaction in Mouse Radiation Chimeras. I. Indirect Evidence for Graft-Antihost Activity," J. Immunol. 89, 453 (1962).

Doria, Gino, "Homograft Reaction in Mouse Radiation Chimeras. II. Direct Evidence for Graft-Antihost Activity," J. Immunol. 89, 459 (1962).

Evans, R. B., III, G. M. Watson, and J. Truitt, "Interdiffusion of Gases in a Low Permeability Graphite at Uniform Pressure," J. Appl. Phys. 33, 2682 (1962).

Hollaender, Alexander (author of "Introduction"), "Symposium on Specificity of Cell Differentiation and Interaction," J. Cellular Comp. Physiol. 60 (suppl 1), 207 pp (1962).

Jacobson, K. B., "Ribonucleotide of RNA: Separation by Chromatography on Paper Sheets of Diethylaminoethylcellulose," Science 138, 515 (1962).

Jagger, John, and R. S. Stafford, "Biological and Physical Ranges of Photoprotection from Ultraviolet Damage in Microorganisms," Photochem. Photobiol. 1, 245 (1962).

Kenney, F. T., "Induction of Tyrosine-α-ketoglutarate Transaminase in Rat Liver. IV. Evidence for an Increase in the Rate of Enzyme Synthesis," J. Biol. Chem. 237, 3495 (1962).

Kimball, R. F., and Stella W. Perdue, "Quantitative Cytochemical Studies on Paramecium. V. Autoradiographic Studies of Nucleic Acid Syntheses," Exptl. Cell Res. 27, 405 (1962).

Löbbecke, E.-A., and R. C. von Borstel, "Mutational Response of Habrobracon Oocytes in Metaphase and Prophase to Ethyl Methanesulfonate and Nitrogen Mustard," Genetics 47, 853 (1962).

Mackin, R. J., Jr., and P. R. Bell, "High-Energy Injection for Controlled Fusion," Nucleonics 20(11), 58 (1962).

Macklin, R. L., G. de Saussure, J. D. Kington, and W. S. Lyon, "Manganese Bath Measurements of η of Pu^{239}," Nucl. Sci. Eng. 14, 101 (1962).

Makinodan, Takashi, and J. F. Albright, "Cellular Variation During Immune Response; One Possible Model of Cellular Differentiation," J. Cellular Comp. Physiol. 60 (suppl 1), 129 (1962).

Manly, W. D., and J. H. Coobs, "The Experimental Gas-Cooled Reactor," pp 49–82 in Nuclear Metallurgy, vol 8, IMD Spec. Rept. Ser. No. 11, The Metallurgy Society of AIME, 1962.

McDaniels, D. K., D. L. Hendrie, R. H. Bassel, and G. R. Satchler, "Alpha-Gamma Angular Correlations and the Distorted-Waves Theory," Phys. Letters 1, 295 (1962).

Meyer, Axel, and R. B. Murray, "Effect of Energetic Secondary Electrons on the Scintillation Process in Alkali Halide Crystals," Phys. Rev. 128, 98 (1962).

Monesi, Valerio, "Autoradiographic Study of DNA Synthesis and the Cell Cycle in Spermatogonia and Spermatocytes of Mouse Testis, Using Tritiated Thymidine," J. Cell Biol. 14, 1 (1962).

Morgan, J. G., M. F. Osborne, and O. Sisman, "Irradiation Effects in the EGCR Fuel," Nucl. Sci. Eng. 14, 69 (1962).

Murray, R. B., "Scintillation Counters," p 82 in Nuclear Instruments and Their Uses, vol I (ed. by A. H. Snell), Wiley, New York, 1962.

Noggle, T. S., "Critical Shear Stress for Slip," p 508 in Encyclopaedic Dictionary of Physics, vol 6, Pergamon, London, 1962.

Novelli, G. D., "Mechanisms Involved in the Control of Enzyme Synthesis," p 435 in The Molecular Basis of Neoplasia (ed. by R. W. Cumley, Marilyn Abbott, et al.), University of Texas Press, Austin, 1962.

Overholser, L. G., and J. P. Blakely, "The Degassing Behavior of Commercial Graphites," p 194 in Proceedings of the Fifth Conference on Carbon, Pergamon, New York, 1962.

Palko, A. A., G. M. Begun, and L. Landau, "Equilibrium Constant for Boron Isotope Exchange Between BF_3 and $BF_3 \cdot O(CH_3)_2$," J. Chem. Phys. 37, 552 (1962).

Picklesimer, M. L., and S. T. Sekula, "Superconducting Transition Temperature of Purified Technetium," Phys. Rev. Letters 9, 254 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. II. Position of the Hemoglobin Locus with Respect to Albinism and Shaker-1 Loci," J. Heredity 53, 73 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. III. Heterogeneity of Electrophoretically Indistinguishable Single-Type Hemoglobins," J. Heredity 53, 75 (1962).

Popp, R. A., "Studies on the Mouse Hemoglobin Loci. IV. Independent Segregation of the Hb and Sol: Effect of the Loci on the Electrophoretic and Solubility Properties of Hemoglobins," J. Heredity 53, 77 (1962).

Rabson, Robert, N. E. Tolbert, and P. C. Kearney, "Formation of Serine and Glyceric Acid by the Glycolate Pathway," Arch. Biochem. Biophys. 98, 154 (1962).

Robinson, M. T., "Deduction of Ion Ranges in Solids from Collection Experiments," Appl. Phys. Letters 1, 49 (1962).

Robinson, R. L., N. R. Johnson, and E. Eichler, "Decay of Cs^{132}," Phys. Rev. 128, 252 (1962).

Russell, W. L., "An Augmenting Effect of Dose Fractionation on Radiation-Induced Mutation Rate in Mice," Proc. Natl. Acad. Sci. U.S. 48, 1724 (1962).

Sherwood, J. E., "A Source of Polarized Ions," Nucl. Instr. Methods 15, 103 (1962).

Warkany, Josef, E. H. Y. Chu, and Emanuel Kauder, "Male Pseudohermaphroditism and Chromosomal Mosaicism," Am. Diseases Children 104, 172 (1962).

Weaver, C. F., and R. E. Thoma, "Production of Single Crystals of Lithium Fluoride with Selected Isotopic Ratios of Lithium," The Branched Chain 18(2), 12 (1962).

Wechsler, M. S., and R. G. Berggren, "Radiation Embrittlement of Reactor Pressure Vessels," Nucl. Safety 4, 42 (1962).

Williams, D. B., "Sensitivity of Spathidium spathula to Low Doses of X Radiation," J. Protozool. 9, 119 (1962).

Wittels, M. C., F. A. Sherrill, and F. W. Young, Jr., "X-Ray Observations of Nearly Perfect Copper Single Crystals," Appl. Phys. Letters 1, 22 (1962).

Wolff, Sheldon, "The Kinetics for Two-Break Chromosome Exchanges," J. Theoret. Biol. 3, 304 (1962).

Yamada, Tuneo, "The Inductive Phenomenon as a Tool for Understanding the Basic Mechanism of Differentiation," J. Cellular Comp. Physiol. 60 (suppl 1), 49 (1962).

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