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HIGH TEMPERATURE CHEMISTRY

Progress Report

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ABSTRACT

Activities are described under the topics of Education, Publications and Talks, Research Progress Highlights, Space and Facilities, Level of Activity, and Miscellaneous.

The educational aspects of the program emphasize broad education in high temperature chemistry and detailed training in one or more areas. One additional graduate from the program is scheduled to enter employment at one of the ERDA laboratories.

Current research is reported for the high temperature thermodynamics and vaporization of the titanium oxides, the vaporization of the rare-earth borides, the phase studies on the Zr-Nb-O system, the studies on high-molecular weight inorganic species, and the kinetic studies on high-temperature vaporization processes.

INTRODUCTION

This Progress Report is divided into six parts which describe Education, Publications and Papers at Meetings, Research Progress Highlights, Space and Facilities, Level of Activity, and Miscellaneous.

EDUCATION

The education of graduate students, undergraduate students, and postdoctoral research associates in high temperature chemistry and associated fields of interest to the Energy Research and Development Administration is one of the continuing and most important purposes of this contract. Activities under this contract have been a prime source of educated and trained manpower for nearly the entire lifetime of AEC, and this flow of personnel continues under ERDA.

Two developments of note occurred during the past year. Dr. Robert G. Behrens, who was a postdoctoral research associate under the contract, has accepted an offer of a position in CMB-3 at Los Alamos Scientific Laboratory effective in mid-November. Dr. Bruce R. Conard, who was a postdoctoral research associate under the contract, after considerable evaluation of his opportunities, declined an offer for a position in the Chemistry Division at Argonne National Laboratory, in order to remain at International Nickel.

Tables I, II, and III summarize the past and present educational products of the program. Table I gives in chronological order of graduation, the names, the dates, and the locations of the scientists who have completed education in high temperature chemistry at the University of Kansas. In Table II, the same information is given, but the names are arranged according to the type of installation. Table III gives the names of the people currently in high temperature research. Twenty men have earned their Ph.D. degrees; nineteen postdoctoral research associates have completed their work; six have

earned the M.S. degree; one faculty member from another institution has taken his sabbatical leave here. These scientists and their accomplishments attest to the educational value of the program. Sixteen are in universities, two in colleges, nine--one more than last year--in ERDA laboratories, five in other research establishments, ten in industry, two in school, and two uncertain. The number of these in high temperature research is probably about 27 out of 46.

These scientists have performed exceptionally well. Of the people whose names are listed in Tables I and II, at least fourteen have substantial international reputations because of their research. The accomplishments of the people in the ERDA laboratories, Ackermann, Leitnaker, Smith, Hobrock, Unruh, Jackson, Peterson, and S.L. Bennett, and Franzen, who is listed at Iowa State University and also in the Ames Laboratory, have been substantial in the Energy Program. In the ERDA laboratories at least five people, Leitnaker, Franzen, Smith, Unruh and Hobrock, have planning and supervisory responsibilities, and Ackermann is assuming a more important role at Argonne as well as on the international scene. Unruh was promoted at Battelle Northwest to manager of Occupational and Environment Safety Department. Spear served on the Scientific Committee for the Fifth International Symposium on Boron and Borides held in Bordeaux, France. Former coworkers Milne and Greene now at Midwest Research Institute are studying coal, an important ingredient in the nation's energy planning.

Of the seven multiprogram laboratories, Argonne, Oak Ridge, Lawrence Livermore, Lawrence Berkeley, Brookhaven, Pacific Northwest and Los Alamos, graduates from the program are in five of these seven laboratories. Of the specialized physical research laboratories, one of the graduates is at Ames; of the production, development and fabrication sites, one is at Savannah River; and of the weapons fabrication complex, one is at Mound Laboratories. Much of the work performed by these men is in the high temperature field.

The Midwest High Temperature Chemistry Conference was held during the summer of 1975 in Toledo, Ohio. The chairman was Prof. Jimmie G. Edwards, who was a postdoctoral research associate under the contract. The chairman-elect for the 1977 conference is Prof. Phillip G. Wahlbeck, also a former research associate under the contract. Attending the meeting in Toledo were fourteen present and former students and seven present and former postdoctoral research associates. Almost all of them reported on their work.

In order to broaden the exposure of the students currently on the scene, seminars are scheduled and conversations with visitors are arranged. Table IV lists the fifteen seminar talks of more or less interest to the high temperature scientists. Of these four were presented by scientists who came especially to the high temperature group. In addition, less formal visits by the following occurred: Leo Brewer in November, Thomas A. Milne in November and September, Joseph Brom in October, and James M. Leitnaker in October.

PUBLICATIONS AND PAPER AT MEETINGS

The permanent, public record is contained in two published articles, and one article accepted for publication, detailed in Table V. Others are in preparation. The principal investigator hopes soon to finish one on the Ti-W-O system, one or two on the kinetics of vaporization of cuprous chloride, and one on the B-S-Si system.

Professor Gilles attended the Fourth International Conference on Chemical Thermodynamics in Montpellier, France, in August; visited the solar furnaces at Odeillo, France; attended the 28th IUPAC Conference in Madrid, Spain in September; and attended the Fifth International Symposium on Boron and Borides in Bordeaux, France, also in September. A trip report was duly submitted as required.

Three invited talks and five contributed talks are described in Table VI.

RESEARCH HIGHLIGHTS

The completed work is described in the publications. Reprints and manuscripts submitted for publication have been submitted to the contracting office in the usual fashion; the contents of those published will not be repeated here. The work will be described in categories as described in the Proposed Technical Program submitted a year ago;

(A) the vaporization behavior of binary and ternary borides, oxides, and sulfides; (B) the phase behavior of refractory systems whose vaporization behavior may be studied; (C) the properties of complex inorganic gaseous substances; and (D) the kinetics of high-temperature vaporization reactions. Another category, (E) computer programming, will be described briefly.

(A) Vaporization Behavior of Binary and Ternary Borides, Oxides, and Sulfides. The Titanium-Oxygen System. Two valiant, but unsuccessful, attempts were made to establish the extent of non-stoichiometry, or the width of the homogeneity range, in Ti_3O_5 through mass spectrometric measurements. As paper number A-85 indicates, mass spectrometric measurements should be suitable for establishing this property from measurements taken with a system at the temperature of interest instead of from measurements on quenched samples. Two samples, each of known composition, but at opposite ends of the Ti_3O_5 phase field are used. Inasmuch as the Ti_3O_5 phase contains the congruently vaporizing solution, the compositions of the two samples, if the temperatures are the same, should approach the same final composition. For each sample, measurements of the intensities of TiO_2 and TiO over the entire course of an exhaustive vaporization of the sample gives the width of the phase and the ratio of mass spectrometric sensitivities for TiO_2 and TiO . The first attempt was made during the summer; the second, in the fall. During the spring the new extension housing was incorporated into the Nuclide vacuum system, and the quadrupole mass spectrometer was inserted through one of the ports of the extension housing. The plan was to use the quadrupole because the period for the cyclic

measurement of the TiO_2^+ and TiO^+ intensities was about two and one-half seconds instead of about twenty minutes with the magnetic mass spectrometer. Thus, chemical phenomena on a time scale only about 0.002 as long as that required for the Nuclide could be studied. This attempt was unsuccessful because the intensities of the ions detected by the quadrupole mass spectrometer were insufficient for use. The insertion of the extension housing moved the sample farther away from the ion source region. When the sample was moved closer by extending the support rods, the autumn attempt was made. Unfortunately, again the quadrupole signals were not great enough. We have some tentative conclusions about the sensitivity for the quadrupole instrument. During the year one manuscript on the titanium-oxygen system was accepted for publication. Currently, plans are being made for a different attack on the titanium-oxygen system.

The Rare-Earth-Boron Systems. During the past year Dr. Liu has prepared samples of several rare-earth borides of formula MB_4 and MB_6 . These have been prepared by arc melting either mixtures of boron and the rare-earth oxide, or mixtures of boron and the rare-earth metal. He has perfected methods of chemical analysis on these samples, and has characterized them by means of x-ray diffraction. He has annealed some of them in high-vacuum by induction heating. The samples are therefore ready for mass spectrometric vaporization investigations. The work should proceed directly.

The Rare-Earth Sulfides. An undergraduate student, Mr. Huycke, carried out some preliminary experiments prior to heating some rare-earth sulfides. He was not able, however, to accomplish much in this activity before he graduated.

(B) The Phase Behavior of Refractory Systems Whose Vaporization Behavior May be Studied. Mr. Gary H. Rinehart has prepared samples in the zirconium-niobium-oxygen system and is in the process of characterizing the phase relationships in this system. This work is preliminary to a study of the vaporization properties of this ternary

system and the properties of the expected complex inorganic gaseous products. The samples are characterized according to their synthetic compositions and according to their x-ray diffraction patterns. Preparations of reduced samples are accomplished by means of prolonged heating at about 1000° in vycor tubes; of fully oxidized samples in air at 1250° .

(C) Properties of Complex Inorganic Gaseous Substances. Mr. Rinehart has studied the boron-sulfur-silicon system by examining mass spectrometric charts taken previously. The results indicate that complex ternary gaseous species containing as many as six or seven silicon atoms have been identified. This work is nearly ready for final submission of a manuscript.

When Mr. Rinehart completes the necessary minimal phase work on the zirconium-niobium-oxygen system, he plans to investigate mass spectrometrically several samples in this ternary system in order to deduce the properties of the complex ternary gaseous species. The apparatus is ready for these studies.

(D) The Kinetics of High-Temperature Vaporization Reactions. During the year the direction of this work was set by the choice of elemental selenium as the most appropriate substance to investigate some of the notions associated with rates of vaporization. The principal reasons leading to the choice of selenium are described in the accompanying proposed technical program. Graphite crucibles have been machined. Samples of very pure selenium have been obtained. The quadrupole mass spectrometer and its associated vacuum system are operable. Some of the programs for the associated computer and data acquisition system are available. The torsion vaporization apparatus is available. Hence, the experimental work on this problem should be underway in the next several weeks.

(E) Computer Programming. Four achievements have been reached during the past year. Mr. Huycke has re-segmented several data acquisition programs so that they will fit into an 8k machine, and hence will be useful in connection with the quadrupole mass spectrometer and the smaller Hewlett-Packard computer. He also completed four data retrieval programs that can now be used for the previously acquired data. In addition, he

corrected one of the magnetic tape storage programs.

Mr. Sheldon revised some of the data acquisition programs previously existing so that they could be used together in an effective way for the exhaustion experiments with the titanium-oxygen system.

Mr. Peters completed the work on four major programs that enable the small Hewlett-Packard computer in the laboratory to communicate effectively with the intermediate-sized Modcomp computer in the Chemical Physics Trilevel Computer Network. These programming tasks were of a major character.

Finally, Mr. Peters has been experimenting with several programs that are to run under a real-time executive operating system (RTE) in the Hewlett-Packard 2100A computer. The purpose of these experimental activities is to allow programs under RTE to access files on discs that were created under a disc operating system; to investigate the way in which the so-called privileged interrupt card will be used under RTE; and to investigate the changes that must be made in our data acquisition and retrieval programs to run under RTE; and finally to see what changes must be made in instrument drivers in order to operate under RTE.

To date some 200 or 250 programs have been written and are immediately useful. Three principal attitudes are used in the writing of programs. The first is that the small computer is not a calculator; rather it is an instrument. The second is that the programs are written in modular form with many versatile subroutines. The third is that each program is superbly documented so that its purpose and use can be understood; and so that its code can be understood after the writer has gone.

SPACE AND FACILITIES

The extension housing that would allow the neutral beam modulation apparatus and the quadrupole mass spectrometer to be used in conjunction with the Nuclide was welded and put into service.

The new pyrometer that was on order at the end of the previous year arrived and has been put into service.

An oscilloscope purchased with University funds to replace one that had been stolen in early 1974 arrived and has been put into service.

The Chemical Physics Trilevel Computer Network is now fully operational as far as the connection between the high-temperature laboratory and the intermediate computer is concerned. During the past year several milestones were passed. In December, the quadrupole mass spectrometer and associated digital voltmeter, pulse-counting scaler, and oscilloscope were attached to a Hewlett-Packard 2116B digital computer, which in turn was connected to the Modcomp II intermediate-sized computer one hundred feet away. From the Hewlett-Packard computer in the laboratory a disc operating system residing on a disc at the Modcomp site was loaded into the Hewlett-Packard computer. Programs similarly stored were loaded through the operating system and were executed in the Hewlett-Packard computer. These programs called for data from the instruments, received data, and stored them away on the disc at the Modcomp site. In October, the programming for the Modcomp and for a Hewlett-Packard computer with associated local magnetic disc in the laboratory was complete. Now on-line transfer of information can occur between the Modcomp and either a Hewlett-Packard computer without a disc or a Hewlett-Packard computer with a disc. The outstanding feature of this network is that a laboratory with a reasonably small investment in a small computer at an experimental site can have real-time access to a reasonably powerful intermediate-level computer and its associated high-quality peripheral devices.

The resistance heating assembly for the Nuclide mass spectrometer is on order.

Some of the difficulties described last year with instabilities in the Nuclide high-temperature mass spectrometer still persist. These are gradually being cleared up. For many experiments of short duration the instabilities are of minor concern, but they are extremely troublesome for a long-term experiment. The hope is that these difficulties can be resolved reasonably soon.

LEVEL OF ACTIVITY

The employment of personnel occurred at nearly the level specified in the revised budget. Prof. J. Edward Bennett was employed one month during the summer when the indications were that Dr. Liu would be leaving in November. The funds for Prof. Bennett ultimately came from the technician and junior systems analysis category. In addition an undergraduate research assistant, Mr. Edward C. Huycke, worked in the laboratory during the spring semester without pay.

MISCELLANEOUS

Several activities at the national and international level may be mentioned. 1. Professor Gilles was reelected to the Board of Trustees of Argonne Universities Association, and was elected to its Executive Committee. 2. He serves as the AUA liaison person with the ANL Chem. Eng. Division Review Committee. 3. He continues to serve as an Associate Member of the International Union of Pure and Applied Chemistry Commission II.3, High Temperatures and Refractory Materials. 4. He served again on the Review Panel for the Inorganic Materials Research Division of Lawrence Berkeley Laboratory in January. 5. He continues to serve on the Editorial Board of High Temperature Science. 6. He serves on the Editorial Board of Advances in High Temperature. 7. He served as chairman of one of the sessions at the Fifth International Symposium on Boron and Borides held in Bordeaux, France in September.

On the local level: 1. Professor Gilles continues to serve on the Committee on Graduate Studies of the College of Liberal Arts and Sciences. 2. He serves on the Board of Directors of the University of Kansas Center for Research, Inc. 3. His wife continues to serve on the Board of Education of Unified School District No. 497 encompassing the Lawrence community and surrounding rural areas.

TABLE I
Scientists Trained in High Temperature Chemistry
at the University of Kansas

<u>Name</u>	<u>Degree</u>	<u>Year</u>	<u>Present Location</u>
Margrave, John L.	Ph.D.	1950	Department of Chemistry, Rice University
Pollock, Bernard D.	Ph.D.	1953	Explosives Laboratory, Picatinny Arsenal
Wheatley, Quentin D.	Ph.D.	1954	Electrochem., du Pont, Niagara Falls
Milne, Thomas A.	Ph.D.	1954	Physical Science Div., Midwest Research Institute
Ackermann, Raymond J.	Ph.D.	1955	Chemistry Div., Argonne National Laboratory
Robson, Harry E.	Ph.D.	1958	Esso Research Laboratories, Baton Rouge
Carlson, K. Douglas	Ph.D.	1960	Dept. of Chemistry, Case Western Reserve University
Cater, E. David	Ph.D.	1960	Dept. of Chemistry, University of Iowa
Leitnaker, James M.	Ph.D.	1960	Metals & Ceramics, Oak Ridge National Laboratory
Plante, Ernest R.	Ph.D.	1960	U. S. National Bureau of Standards
Knarr, Warren A.	Ph.D.	1960	Pharmacy Student, University of Iowa
Franzen, Hugo F.	Ph.D.	1962	Dept. of Chemistry & Ames Lab., Iowa State Univ.
Smith, P. Kent	Ph.D.	1964	Nuclear Mat. Div., Savannah River Lab., du Pont
Killingbeck, Stanley	Ph.D.	1964	Dept. of Chemistry, Central Missouri State
Lin, Sin-Shong	Ph.D.	1966	Army Mat. & Mechanics Res., Watertown, Mass.
Spear, Karl E.	Ph.D.	1967	Mat. Res. Lab & Mat. Science Dept., Penn State
Chen, Horng-yih	Ph.D.	1968	Central Res. Dept., du Pont, Wilmington, Delaware
Nordine, Paul C.	Ph.D.	1970	Dept. of Chemical Engineering, Yale
Wu, Richard	Ph.D.	1971	Dept. of Chemistry, Wright State University
Peterson, Dean E.	Ph.D.	1972	CMB-5 Los Alamos Scientific Laboratory
Eick, Harry A.	Post Ph.D.	1958	Dept. of Chem., Michigan State University
Wahlbeck, Phillip G.	Post Ph.D.	1960	Dept. of Chemistry, Wichita State University
Wall, John G. L.	Post Ph.D.	1960	Monsanto Chem. Ltd., Belgium
Westman, Sven	Post Ph.D.	1962	Inst. for Inorganic Chem., Univ. of Stockholm
Greene, Frank T.	Post Ph.D.	1962	Physical Science Div., Midwest Research Inst.
Wang, Chih Chun	Post Ph.D.	1963	RCA Laboratories, Princeton, N. J.
Wiedemeier, Heribert	Post Ph.D.	1964	Dept. of Chem., Rensselaer Polytechnic Institute
Lewis, Gordon	Post Ph.D.	1964	Dept. of Ceramic Eng., University of Missouri, Rolla
Hobrock, Don L.	Post Ph.D.	1965	Mound Laboratory, Miamisburg, Ohio
Edwards, Jimmie G.	Post Ph.D.	1967	Dept. of Chemistry, University of Toledo
Petzel, Thomas	Post Ph.D.	1967	Chem. Lab., University of Freiburg, Germany
Bennett, Stephen L.	Post Ph.D.	1968	Metals & Ceramics, Oak Ridge, National Laboratory
Bergner, Dieter	Post Ph.D.	1968	Farbwerke Hoechst, Frankfurt, Germany
Hampson, Peter J.	Post Ph.D.	1970	Johnson Matthey Chemicals Ltd., Royston, England
Mertin, Wilhelm	Post Ph.D.	1971	Inorg. Chem. Inst., Univ. of Giessen, Germany
Castles, Jeffrey R.	Post Ph.D.	1971	Melbourne, Australia
Conard, Bruce R.	Post Ph.D.	1972	International Nickel, Ltd., Ontario, Canada
Sullivan, C. Larry	Post Ph.D.	1973	Avila College, Kansas City, Missouri
Bennett, J. Edward	Vis. Fac.	1974	Department of Chem., Arkansas State University
Behrens, Robert G.	Post Ph.D.	1974	CMB-3 Los Alamos Scientific Laboratory (November)
Richardson, Paul J	M.S.	1950	Law Student, University of Toledo
Unruh, Carl M.	M.S.	1954	Battelle-Northwest, Richland, Washington
Jackson, Donald D.	M.S.	1958	Lawrence Radiation Lab., Livermore, California
Ernick, Frederick	M.S.	1961	Silicon Transistor Corp., Garden City, NY
Stone, G. Duane	M.S.	1962	Parlin Res. Lab., du Pont, Wilmington, Delaware
Werner, Donald W.	M.S.	1965	Uncertain

TABLE II

Distribution of Scientists Trained in High Temperature Chemistry
at the University of Kansas

<u>Type of Institution</u>	<u>People</u>
Universities	Margrave, Carlson, Cater, Franzen, Spear Eick, Wahlbeck, Westman, Wiedemeier, Lewis, Edwards, Petzel, Mertin, J.E. Bennett, Nordine, Wu
College	Killingbeck, Sullivan
ERDA Laboratories	Ackermann, Leitnaker, Smith, Hobrock, Unruh, Jackson, Peterson, S. L. Bennett, Behrens (Nov.)
Research Establishments	
Army Materials & Mechanics Research Midwest Research Institute	Lin Milne, Greene
National Bureau of Standards Picatinny Arsenal	Plante Pollock
Industry	Wheatley, Robson, Wall, Wang, Bergner, Hampson, Ernack, Stone, Chen, Conard
Postdoctoral Study	None
Student	Knarr, Richardson
Uncertain	Werner, Castles

TABLE III

Scientists Currently in High Temperature Chemistry Research
at the University of Kansas

<u>Name</u>	<u>Degree</u>	<u>Year</u>	<u>Remarks</u>
Sheldon, Robert	Ph.D.	1976	
Huang, John	Ph.D.	1976	
Rinehart, Gary	Ph.D.	1977	
Liu, Ming-Biann	Post Ph.D.	1976	Educated with Wahlbeck at Illinois Inst. of Technology

TABLE IV

Visitors at the University of Kansas
Of Interest to High Temperature Chemists
For the Period 1974, November 1, to 1975, October 31

<u>No.</u>	<u>Visitor</u>	<u>Title of Talk</u>	<u>Date Visited</u>
V-234	Dr. L. V. Interrante General Electric Corp. Schenectady, New York	"Molecular Solids with Unusual Solid State Properties."	75, Jan. 12
V-235	Dr. Kenneth Sauer Dept. of Chemistry University of California Berkeley, California	"Energy Conversion in Photosynthetic Membranes."	75, Feb. 24
V-236	Dr. George Barisas Dept. of Chemistry University of Colorado Boulder, Colorado	"Microcalorimetry Studies of Heme-Protein Ligand Interactions."	75, Mar. 18
V-237	Dr. P. Gary Eller Los Alamos Scientific Lab. Los Alamos, New Mexico	"Bonding, Magnetism, and Structure in Oxygen-Bridged Transition Metal Complexes."	75, Mar. 20
V-238	Prof. Anthony M. Dean Dept. of Chemistry University of Missouri Columbia, Missouri	"Shock Tube Kinetics."	75, Mar. 21
V-239	Prof. F. Sherwood Rowland University of California Irvine, California	"Freons in the Atmosphere."	75, Apr. 3
V-240	Dr. Peter M. Rentzepis Bell Laboratories Murray Hill, N. J.	"Picosecond Spectroscopy and Molecular Relaxation - Chemical and Biochemical Applications."	75, Apr. 7
V-241	Dr. Marvin Bishop Howard University Washington, D. C.	"Computer Simulation of the Structure and Dynamics of Simple Liquids and Liquid Crystals."	75, Apr. 9
V-242	Prof. Gary L. Bertrand Dept. of Chemistry University of Missouri Rolla, Missouri	"Calorimetric Methods of Investigation of Hydrogen Bonds."	75, Apr. 18

- V-243 Dr. Joseph Brom "Pseudo Gas Phase Laser Photo- 75, Apr. 25
University of California luminescence Spectroscopy."
Santa Barbara, Calif.
- V-244 Dr. John D. Baldeschwieler "The Application of New Physical 75, Apr. 29
California Institute of Methods."
Technology
Pasadena, California
- V-245 Dr. James M. Leitnaker "Materials Problems in Nuclear 75, May 30
Metals Ceramic Division Reactors."
Oak Ridge National Lab.
Oak Ridge, Tenn.
- V-246 Prof. Karl E. Spear "High Temperature Research in Materials 75, May 30
Pennsylvania State Univ. Science."
Materials Science Dept.
State College, Pa.
- V-247 Dr. Joel Tellinghuisen "Noble Gas Diatomic Halides." 75, June 26
N.O.A.A.
Boulder, Colorado
- V-248 Dr. Jean-Pierre Coutures "Solar Furnaces and High Temperature 75, Oct. 3
Laboratoire des Ultra- Physical Chemistry Research."
Refractaires,
Centre National de la
Recherche Scientifique
Odeillo-Font-Romeau, France

TABLE V
Publications Resulting From
High Temperature Chemistry Research

Articles Published

- A-85. "High-Temperature Vaporization and Mass Spectrometric Measurement of the Extent of Non-Stoichiometry in Oxide Phases." Paul W. Gilles, Bruce R. Conard, Robert I. Sheldon, and J. Edward Bennett. *Thermodynamics of Nuclear Materials 1974, Vol. II*. International Atomic Energy Agency, Vienna, pp. 499-504(1975). COO-1140-213.
- A-86. "Chemistry of Vaporization of Refractory Materials." Paul W. Gilles. *J. Amer. Ceramic Soc.*, 58[7-8] 279-284(1975). July-August. COO-1140-209.

Articles Accepted for Publication

- COO-1140-215. "High-Temperature Vaporization and Thermodynamics of the Titanium Oxides. IX. Fragmentation of TiO_2^+ ." Bruce R. Conard, J. Edward Bennett, and Paul W. Gilles. *J. Chem. Phys.*

TABLE VI

Talks and Papers at Meetings

- T-184 Department of Chemistry, University of Toledo, Toledo, Ohio. Invited talk -- "Real-Time Computers in Chemical Research." Paul W. Gilles. 1974, December 2.
- T-185 The Midwest High Temperature Chemistry Conference, Toledo, Ohio. "High-Temperature Data Acquisition and Equipment Control with Digital Computers." Paul W. Gilles. 1975, June 16.
- T-186 The Midwest High Temperature Chemistry Conference, Toledo, Ohio. "Vaporization Studies of the Rare-Earth Borides." Ming-Biann Liu and Paul W. Gilles. 1975, June 16.
- T-187 The Midwest High Temperature Chemistry Conference, Toledo, Ohio. "Mass Spectrometric Measurement of the Extent of Non-Stoichiometry of Oxide Phases." Robert I. Sheldon and Paul W. Gilles. 1975, June 16.
- T-188 The Midwest High Temperature Chemistry Conference, Toledo, Ohio. "Computerization of a Quadrupole Mass Spectrometer for High Temperature Kinetic Studies." Y. K. Huang and Paul W. Gilles. 1975, June 16.
- T-189 The Midwest High Temperature Chemistry Conference, Toledo, Ohio. "High-Molecular Weight Gaseous Species in the Boron-Sulfur-Silicon System." Gary H. Rinehart and Paul W. Gilles. 1975, June 16.
- T-190 Fourth International Conference on Chemical Thermodynamics, Montpellier, France. Invited paper on a panel discussion, "Vapor Pressure Standards." Paul W. Gilles. 1975, September 26.
- T-191 Symposium on High Temperature Processes Induced in Materials by Absorption of Radiation, 148th Meeting of the Electrochemical Society, Dallas, Texas. Invited talk -- "Chemistry of Vaporization of High Temperature Materials." Ming-Biann Liu and Paul W. Gilles. 1975, October 9.