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ADVANCED NUCLEAR ROCKET MATERIALS RESEARCH

May 31, 1962

Division of Reactor Development
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Introduction

This report is being circulated to stimulate interest in research on materials for extremely high temperature nuclear rocket applications. It should also guide any interest that might be stimulated so that research effort will be expended on materials believed to be of potential use in advanced nuclear rocket reactors.

We recognize that the immediate U. S. capability to conduct the research suggested is extremely limited. In view of this limited capability we hope that the initial impact of this report will be to encourage competent research organizations to obtain the equipment and experience required to conduct such research.

Frank K. Pittman, Director
Division of Reactor Development

May 31, 1962

A meeting was held on May 9, 1962, in the AEC offices at 1717 H Street, N.W., Washington, D.C. for the purpose of:

- (1) Defining the materials problems inherent in advanced nuclear rockets.
- (2) Selecting the materials that appear most promising for advanced nuclear rockets.
- (3) Considering the available information on the promising materials.
- (4) Listing the materials properties and/or other information that should be obtained and where possible, establishing the relative urgency of the requirement.

The following individuals active in extremely high temperature materials research participated in the meeting:

Robert W. Hall	-	NASA (Lewis Research Center)
Melvin G. Bowman	-	LASL
Haruo Kato	-	Bureau of Mines
Colt D. Pears	-	Southern Research Institute
Harry S. Parker	-	Bureau of Standards
Allen D. Franklin	-	Bureau of Standards
Vincent P. Calkins	-	GE (NMPO)

The AEC and NASA headquarters staffs were represented by:

Merrill J. Whitman	-	AEC - Chairman
William L. R. Rice	-	AEC
F. Carl Schwenk	-	NASA (SNPO)
John E. Morrissey	-	AEC (SNPO)
James Gangler	-	NASA
Harold Hessing	-	NASA

Selection Criteria - It was agreed that materials to be considered would not be eliminated because of weight (density), nuclear cross-section, brittleness, or cost. The minimum requirement was that the material in question have a melting point over 3500° F.

It was agreed that information on any material of interest would include the following:

- A. Compatibility, with
 - (1) Nuclear Fuel
 - (2) Hydrogen
- B. Physical Properties
 - (1) Thermal Expansion
 - (2) Thermal Conductivity
 - (3) Specific Heat
 - (4) Emittance
 - (5) Vapor Pressure
- C. Mechanical Properties
 - (1) Tensile Modulus
 - (2) Stress Rupture
 - (3) Elongation (Ductility)
 - (4) Fabricability

Materials selected as being of interest are as follows: Metals, Carbides, Sulfides, Nitrides, Oxides, and Borides. Each class will be discussed in turn.

I. Metals

Metals of most interest are listed in Table I. The metals osmium and iridium were eliminated because of lack of information on their properties. Before they would be considered for engineering applications, either alloyed or unalloyed, more work of a basic nature needs to be done. The final order agreed upon is as follows: W (thermal reactor use), W-Re alloys, W-Ta alloys, Re, Ta-W alloys, Mo (thermal reactor use), Ta, and Nb (in decreasing order of attractiveness).

W - It is important that the practical limit of uranium dioxide addition to W-UO₂ fuel elements be established. Information should be obtained on the effect of UO₂ loading on: (1) Fabricability, (2) Chemical and Metallurgical stability, (3) Fuel Retention, (4) Performance, and (5) Strength and Physical Properties. It is particularly important that the diffusion coefficient of hydrogen through tungsten as a function of temperature be determined.

Re and Re Alloys - It must be recognized that at present Re is in short supply. This is not considered sufficient justification to eliminate its use. In general, it is necessary that the metallurgy of Re be studied to the same extent as that of tungsten. As with tungsten, it is important that Re, or Re alloys, be evaluated for use as fuel cladding and matrix materials. The diffusion coefficient of hydrogen through Re should be determined as a function of temperature.

Ta and Ta Alloys - The biggest problem with Ta is its susceptibility to hydriding and subsequent disintegration. It is vital that we obtain information on the effect of hydrogen on the mechanical properties of tantalum bearing alloys, with the hope that alloys can be prepared having resistance to hydriding. Data should be obtained on the solubility of hydrogen in tantalum alloy systems (hydrogen uptake rate as a function of temperature and pressure). Research should be initiated to obtain a coating material for Ta that would prevent it from hydriding.

Mo - It is recognized that Mo has an advantage over W with respect to weight, cross-section, and ease of fabrication. It was eliminated because of low strength and high vapor pressure at operating temperatures.

General - No special emphasis on the metal phase diagrams is considered necessary. High temperature X-ray equipment is very badly needed to study refractory metal alloys at high temperatures. For all of these metals it is important that stress-strain curves, rather than simple stress at rupture, be known, since many of them yield continually over the entire stress range at high temperatures.

II. Graphite

A large amount of work is needed on graphite. Included is work on attainment of theoretical density, development of a scientific basis of fabrication technology, development of uniform raw materials, and control of directional thermal and mechanical properties.

III. Carbides

The order of compounds, according to decreasing interest, is as follows: HfC, HfC-ZrC, TaC, MoC, ⁶⁷NbC, GdC, TiC, WC, Mo₃C₂. The list is intended to include the material listed as a single compound and in combination with uranium. WC is given a low rating because of its melting point.

Not included, but of interest, are the compounds UWC₂ and UMoC₂. The stability of these compounds should reduce the loss of uranium by diffusion through the cladding. Also not included is consideration of UC and UC₂. The effort on the carbides of uranium is very extensive and should provide the information desired.

The following information is desired for all the compounds listed, and, in fact, applies equally to the carbides, oxides, nitrides, and borides:

- (1) High temperature mechanical properties as a function of composition (stoichiometry).
- (2) Methods of synthesis and fabrication into useful shapes (thin sheets, rods, etc.).
- (3) Means of controlling composition over a wide temperature range.

Specifically, information is desired on:

- (1) Melting points of nonstoichiometric HfC as a function of composition.
- (2) Mechanical properties of HfC and ZrC as a function of composition.
- (3) Thermal-chemical properties of U bearing ternaries UHfC, UZrC, UTaC and UNbC up to 50 atomic per cent U.

IV. Sulfides

Of the sulfides, only US is of interest. It is desired that information be obtained on melting points, stoichiometry, and the synthesis and fabrication of this material. ANL should provide much of this information within the scope of its existing effort.

V. Nitrides

The nitrides of interest (in decreasing order) are Un, HfN, ZrN, TiN, and BN. A substantial effort is now underway on UN, including a study of synthesis, fabrication, and irradiation stability. The nitrides, in general, are less promising than the carbides. Nitrides clad with W might be useable since WN is not stable at high temperature. It is therefore important that W be studied for possible use as a nitrogen barrier. If it is an acceptable barrier the nitrides should be screened for application.

VI. Oxides

Hydrogen reduction negates the use of oxides for nuclear rocket applications. They are limited also by their brittle behavior. BeO is of interest as a moderator material, and, if temperatures are kept below 1600°C, might have structural applications. Uranium dioxide is of course of interest as a fuel material, but only if clad.

It is felt that a small amount of exploratory research on fused ThO₂ would be helpful to establish its potential as a structural material.

VII. Borides

The borides appear promising as structural materials, since they are not as brittle as the oxides and are more resistant to thermal shock than the oxides and carbides. It is anticipated that they will be compatible with the carbides. Order of preference is not clear, but it is intuitively felt that TaB₂ and ThB₄ would be most interesting to study.

Merrill J. Whitman
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TABLE I.

MATERIALS OF INTEREST FOR NUCLEAR ROCKET APPLICATIONS

A. METALS

W
Re
Ta
Mo
Nb
Os
Ir

B. CARBIDES

Graphite
HfC
ZrC
TaC
NbC
MoC .67 - NbC
GdC
TiC
WC
Mo₃C₂
UWC₂
UMoC₂
Ternary Mixtures

C. URANIUM SULFIDE

D. NITRIDES

UN
HfN
ZrN
TiN
BN

E. OXIDES

UO₂
BeO
ThO₂
ZrO₂
HfO₂
CeO₂ (Ce₂O₃)
MgO

F. BORIDES

TaB₂
ThB₄
HfB₂
ZrB₂
WB
TiB₂