ORNL
Metals And Ceramics Division
HTML - High Temperature Materials Lab.
A Proposed New Facility At ORNL, Aug. 1977
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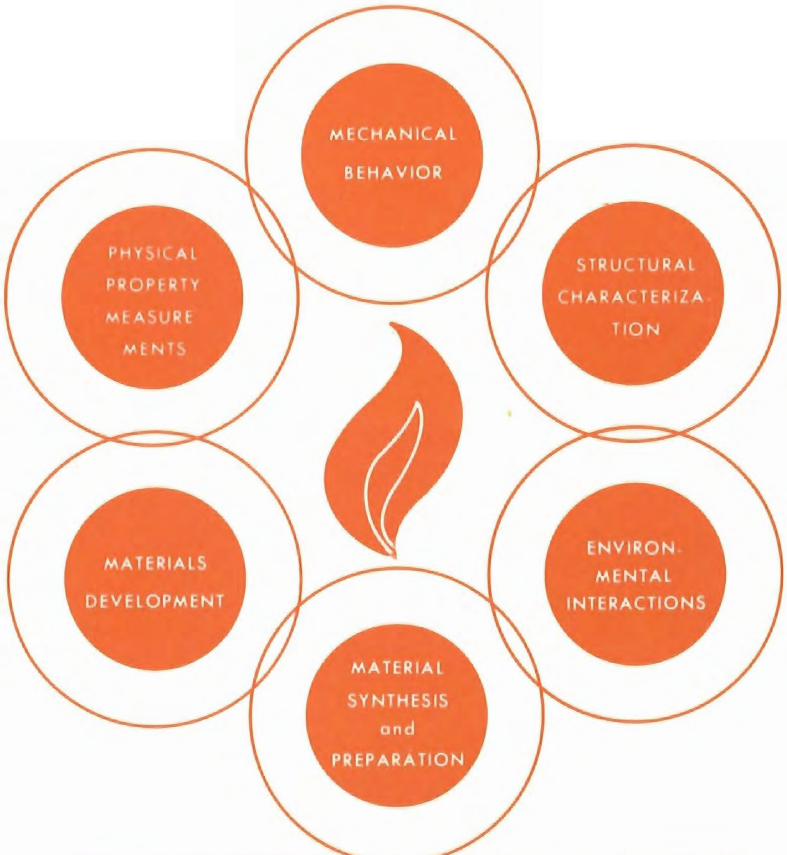
HTML

A PROPOSAL FOR A HIGH TEMPERATURE MATERIALS LABORATORY



OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

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HIGH TEMPERATURE MATERIALS LABORATORY

A PROPOSED NEW FACILITY

at

OAK RIDGE NATIONAL LABORATORY

T. C. Reiley, Editor

AUGUST 1977

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HTML — HIGH TEMPERATURE MATERIALS LABORATORY

1. INTRODUCTION AND SUMMARY

In this document we propose that a new facility, the High Temperature Materials Laboratory (HTML) be built by ERDA/DOE at the Oak Ridge National Laboratory. The objectives of the laboratory include (1) research on the properties of materials and classes of materials at elevated temperatures, and (2) provision of equipment and expertise for specialized materials measurements and materials synthesis at elevated temperatures.

The research performed at HTML will be designed to provide an understanding and useful application of the relationships between a material's properties at elevated temperatures and its structure, composition, and environment. This research will be basic to problem areas in materials and materials processing which are generic to energy systems of near- and long-term interest to ERDA/DOE. The service and support functions fulfilled by HTML would include the synthesis of new and well-characterized materials for ORNL and other laboratories and the measurement of materials' properties at high temperatures and in adverse environments. Thus, HTML may be looked upon as a national resource of equipment and expertise as well as a center for multidisciplinary research in an important area.

The new facilities required for HTML include a major expenditure for new equipment, along with a building to house the equipment and the personnel. It is estimated that approximately $6 million will provide the major new equipment needs, while other equipment will be transferred from existing ORNL facilities. The cost for the HTML building is estimated to be about $11 million for a building having about 80,000 square feet. Available space of this magnitude does not presently exist at ORNL. The total capital cost, including a small amount for equipment transfer, is estimated to be $17.5 million.

This proposal is addressed to the Basic Energy Sciences Division of ERDA/DOE. It is proposed that this Division fund the capital outlay for

HTML, and, further, that this Division provide funding for most of the operational research expenses, as elaborated later in the proposal. The important point made here is that the philosophy governing the majority of research in HTML is that the work be basic studies dedicated to understanding, rather than to system development. This does not exclude research on complex materials that may be used in energy systems; it does limit the amount of work directed toward the development or phenomenological characterization of component materials. HTML would also contain some selected applied research projects chosen to extend or optimize the basic work forming the center of the institute. Thus, HTML would contain a basic research program having projects that extend to current technological problems and to advanced technologies. It will be designed to promote interaction with industrial research interests and visiting industry scientists, as well as scientists from the universities. The significant factor promoting this interaction is the unique, state-of-the-art equipment to be contained in HTML.

Sections 2 and 3 of this proposal describe the reasons for research on materials at elevated temperatures. This is written in terms of general impact on and response to national energy policies and in terms directly related to the technological needs of near- and long-term energy systems. The advantages of a specialized institute such as HTML to ERDA/DOE are considered in Sect. 4. The advisability of locating HTML at Oak Ridge National Laboratory is discussed in Sect. 5. Typical research programs are presented in Sect. 6. Sections 7 and 8 give the details of the required equipment, personnel, operating funding, and building.

The value of a basic research institute such as HTML are many. Certainly there is a pragmatic expectation of a return on the research investment in a research program designed to improve the performance of high temperature materials. Another value which is not so easily estimated is that of the unforseeable breakthroughs in the generally unexplored regime of material behavior at high temperatures. Just as the extension of research into the low temperature regime resulted in the discovery of superconductivity with its economic dividends, so we may expect dividends from the unpredictable breakthroughs awaiting discovery through the work proposed for HTML.

The important facts that describe HTML are summarized below.

Personnel*	
Professional staff	70
Technicians	32
Support personnel	23
Crafts	15
Total	140

Capital costs	
Building (80,000 square feet)	$11,000,000
New equipment and moving expenses for existing equipment	6,500,000
Total	$17,500,000

Operating costs* (per year in FY 77 dollars)	$ 9,000,000
Scheduled completion	Oct. 1, 1981

*At full occupancy and utilization.

2. NEED FOR THE STUDY OF HIGH TEMPERATURE MATERIALS

Until recently, most improvements in man's ability to use heat have arisen through understanding of physical processes and improved design of energy systems. In the last century, however, we can attribute the largest fraction of our successes to improved materials with which to contain and transform heat energy. We have now reached a point at which materials limitations dominate virtually all our advanced concepts for energy use. These limitations are most commonly associated with mechanical or chemical stability at elevated temperatures in adverse environments. In this section of the proposal we cite five general areas in which elevated temperature materials research can affect the energy program in the U.S. These areas are (1) the *efficiency* of the conversion of heat energy, (2) the *reliability* of structural components in service at elevated temperatures, (3) the *feasibility* of certain advanced energy systems, (4) the *conservation* of fuel and scarce materials, and (5) *broad exploratory research* and understanding of materials at high temperatures.

2.1 EFFICIENCY

All of the present energy production systems of consequence, except hydroelectric power production, are heat generation systems. In particular the generation of electrical power by heat energy now results from the burning of fossil fuels (oil, gas, or coal) or from nuclear reactors. The efficiency of the conversion of heat energy into mechanical and then electrical energy is governed by the laws of thermodynamics; that is, the Carnot cycle.

The Carnot cycle sets the upper limit of efficiency, η, for any real power cycle operating between temperatures T_1 and T_2; $\eta = (T_1 - T_2)/T_1$. Because the lower heat rejection temperature, T_2, is usually fixed no lower than ambient, higher efficiencies require higher operating temperatures (Fig. 2.1). Carnot efficiencies of 56 to 59% are predicted for the steam temperatures currently available. The total efficiencies of modern steam power plants are 30 to 40%. However, even though only small changes (5 to 10%) in Carnot efficiency are possible with limited changes

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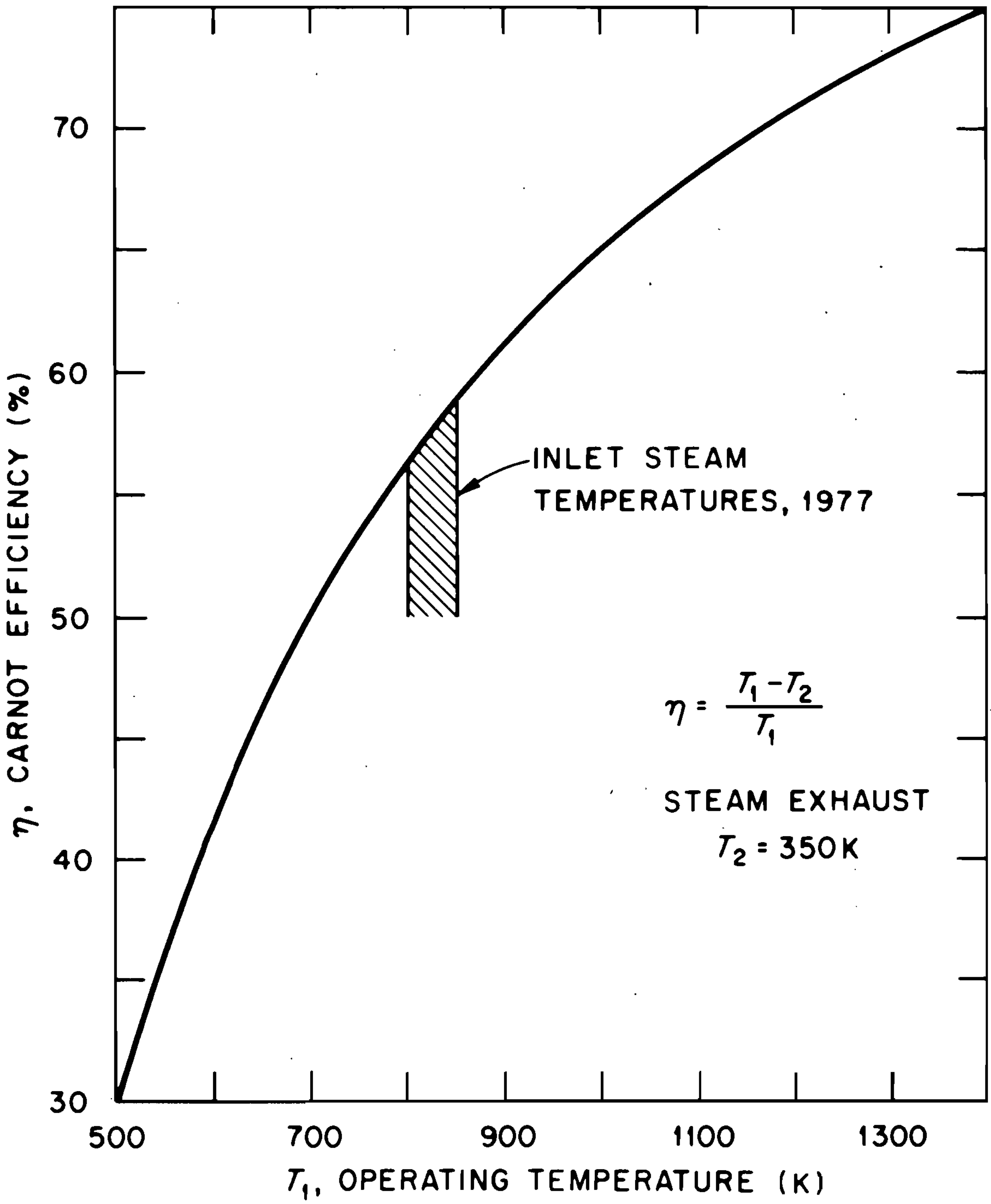

Fig. 2.1. Carnot efficiency vs operating temperature for an ideal heat engine.

in steam temperature, such changes can result in large economic effects. McLean[1] has used data from the Central Electricity Board of the United Kingdom to show that the ∿100°C rise in steam temperature realized from 1948 to the 1970s resulted in an increase of 8% in Carnot efficiency (to 58%). During the same period total power plant efficiency increased from 21 to 30% with the Carnot contribution estimated to be approximately one-third of this. The savings in fuel each year from the improvement in efficiency was determined by calculating the cost of generating each year's supply of electricity using the 1948 efficiency and then subtracting the actual cost that year to obtain the savings. In 1973, for example, these savings were $600 million. It was estimated that the metallurgical improvements, as represented by the Carnot contribution, amounted to approximately one-third of this or $200 million. Thus substantial savings can be obtained with modest increases in efficiency.

The above example is specific to the United Kingdom, but similar figures should apply to the United States. The total U.S. electrical generation in the early 1970s was approximately 8 times that of the United Kingdom.[2] If we use the above U.K. figures for savings due to increased efficiency provided by metallurgical improvements in 1973 and simply multiply by 8, we obtain an estimated savings of $1.6 billion for the U.S. in 1973. Assuming a linear increase in savings with efficiency and operating temperature over the 100°C interval, we may predict a current *annual savings of greater than $16 million for each 1°C rise in operating temperature* (a figure comparable to the cost of HTML).

Increased efficiency will be more and more important in the future due to increasingly expensive fuels. Both the cost of fuel and the large capital investment make increased thermal efficiency a greater economic incentive in large power plants.

Higher efficiencies can be achieved in systems in which a steam turbine and a gas turbine are combined. When the exhaust from a gas turbine is channeled into a boiler, this waste heat can be used to produce steam. Combined cycle total efficiencies comparable to the best steam power installations (~40%) have been achieved, and if turbine gas temperatures of 1450°C could be reached, a cycle total efficiency of 50% is projected.[3] However, severe problems of high temperature material strength and corrosion resistance exist at these temperatures. The development of improved high temperature turbine blade and coating materials will be required if such high thermal efficiencies are to be reached. "Potential cost savings from using higher turbine inlet temperatures are estimated to be several billions of dollars per year."[4] An alternative to the high temperature gas turbine topping cycle which would result in the same high total thermal efficiency (~50%) is a topping cycle that uses potassium vapor.[5] In this cycle the turbine inlet temperature need be only ~850°C. This temperature allows the use of fluidized-bed coal combustion systems, which are limited to about 900°C for good sulfur retention. This lower turbine inlet temperature is also more compatible with the practicable temperatures achievable with fission or fusion power plants. Materials for the potassium boiler tubes also present problems in strength and corrosion resistance.

The efficiency problem is one of saving energy resources — fuel — and therefore money. Thus there is a trade-off between the savings due to increased efficiencies by using higher operating temperatures and the cost of the special materials required for high temperature service. A materials development program in this area will require substantial research efforts in mechanical properties, corrosion and oxidation, alloy design, and materials synthesis.

2.2 RELIABILITY

The chief causes of power plant forced-outage are essentially materials reliability problems. Steam turbines have the highest failure rate of all plant equipment, making up 16% (nuclear plant) to 21% (fossil plant) of the plant forced outages in 1973. Failures in turbine buckets and blades are the most frequent. The failure rate of condenser tubes (mainly a corrosion problem) is the next most frequent. From the analysis of the failure rate of critical steam plant components from these problems, a conservative estimate of the savings from improved materials reliability alone would be approximately $10 billion over a ten year period, based on a recent EPRI report.[6]

At ambient temperature in the absence of a corrosive environment, the life of structural components in nonvibratory service is essentially unlimited, provided the stresses are below the yield strength of the material. However, elevated temperature service makes the prediction of component lifetimes far less reliable due, chiefly, to creep and environmentally induced failure. Creep — time-dependent strain under stress — becomes significant at temperatures near and above a material's recrystallization temperature. A typical creep curve (strain vs time) can be divided into three regions: (1) primary creep, where the structure evolves to some reasonably stable density and configuration of dislocations and the creep rate normally decreases, (2) secondary creep, where a condition closely approximating equilibrium between the competing processes of work hardening and recovery is established such that the creep rate is essentially constant, and (3) tertiary creep, where the creep rate accelerates and fracture occurs.

Data pertaining to the elapsed time and extension that precede tertiary creep are of critical importance in the design of components for service at elevated temperatures. It is thought that the onset of tertiary creep is due to structural or geometrical instabilities. In age-hardening alloys the creep rate may be modified as aging under stress proceeds. In nickel-base (and other high temperature alloys) precipitation of intermediate phases, such as sigma or Laves phases, can affect the creep rate. Additional structural changes that can modify (accelerate) the creep rate include carbide reactions, interactions between precipitate phases, and recovery or recrystallization. Other structural instabilities, such as crack nucleation associated with grain boundary sliding or the precipitation of vacancies into voids, may also encourage tertiary creep and failure. It is not now possible to predict which mechanism controls the onset of tertiary creep and creep ductility in engineering materials.

Environmental degradation of a material is probably the major source of elevated temperature failure requiring premature replacement of a component. Oxidation is a common environmental effect. Metals require either self-protective oxides or coatings for protection against oxidation. Chromium is the chief alloying addition for the creation of self-protective oxides in many materials. In alloys for which self-protecting oxides do not exist or can be degraded easily, protective alloys such as Co-Cr-Al-Y and Fe-Cr-Al-Y are commonly used. Erosion, cyclic stress, and localized attack can break down protective coatings in service. Carburization of stainless steels, vanadium ash attack, sulfidation, hydrogen attack, and molten-salt corrosion are further examples of environmental degradation that can cause premature, and often unpredictable, failures. Stress-corrosion cracking, a serious problem at ambient temperature, is more severe at elevated temperatures due to enhanced corrosion kinetics.

Other stress- and environment-related phenomena that can result in component failure at elevated temperatures include fatigue, creep-fatigue, thermal fatigue, and erosion. A variety of these phenomena, which are only partially understood, can contribute to the poor reliability of materials performance at elevated temperatures. Systematic experiments on model and engineering materials are needed to establish phenomenological cause-effect relationships. Then experimental and theoretical work is required to determine the microscopic mechanisms responsible.

A major difficulty for any advanced energy system operating at elevated temperatures is the unreliability of long-term extrapolations of short-term test data. Mechanical tests are frequently performed over time periods of 1000 to 10,000 hr. Results from these experiments are routinely used to evaluate in-service operation for periods up to and exceeding 100,000 hr. However, the acceleration of mechanical tests can result in deformation mechanisms unlike those dominant in actual service. Concomitant with this difference in deformation mode may be a difference in fracture mode and strain to failure (the criterion that is frequently used to evaluate the overall suitability of a structural material at elevated temperatures). Thus, predictions based on accelerated tests may lead to improper conclusions. In the same category would fall the difficulty in extrapolating corrosion or phase stability information gathered from short-term experiments. The ability to extrapolate properly short-term kinetic data to long-term design criteria is crucial to providing adequate system reliability.

2.3 FEASIBILITY

Another important stimulus for research on high temperature materials is that for many potentially high-efficiency systems, it is impossible to estimate the probability of their success because of deficiencies in materials or understanding of materials at high temperatures. The coal-fired magnetohydrodynamic (MHD) power generator is a significant example of the need for high temperature (≥2000°C) structural ceramics, or, more significantly, the need for material data and characterization in this temperature range. MHD, which offers high thermal efficiency when operated in a combined power cycle (50 to 60%), is blocked by the lack of suitable materials for preheaters, combustors, and generators. Understanding and data on high temperature behavior are so limited that the feasibility of developing critical components such as the electrodes and insulators for the MHD generator cannot be evaluated. Here, the thermal and electrical conductivities, along with erosion and corrosion rates in the proposed MHD environments, are matters open only to limited conjecture. Before MHD can be successfully exploited, we will require fundamental information on high temperature materials behavior. Figure 2.2 shows how far present MHD systems are from economically feasible operating conditions in terms of time of plant operation and level of power output.[7]

Another technology for which the evaluation of a long-range energy system is limited by elevated temperature materials information is magnetic fusion. To date the feasibility of operating a metal first wall at temperatures up to about 500°C has been evaluated. However, above this temperature it is difficult to predict feasibility because of the lack of information on radiation damage, surface sputtering, and mechanical behavior of candidate materials, especially refractory metals.

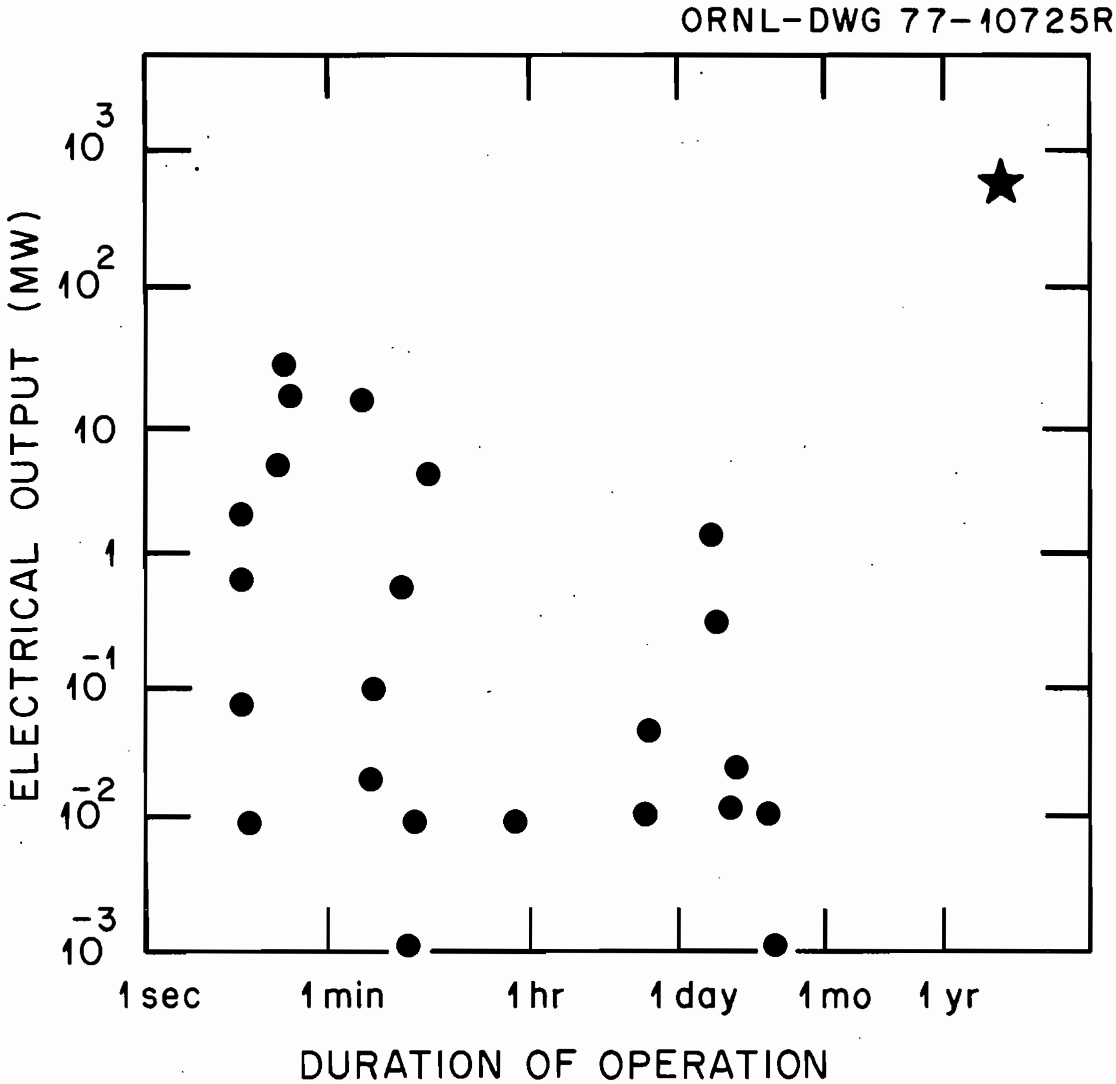

Fig. 2.2. MHD power output vs duration of experiments (through summer 1975) compared to the target for practical or economic feasibility. •, experimental results; ★, target for practical operation. Source: After W. K. Jackson et al., p. 40 in *Proc. 6th Int. Conf. Magnetohydrodynamics Electr. Power Generation*, vol. 5, J. E. Keteis, Ed., Nat. Tech. Inf. Serv., Springfield, Va., 1975.

2.4 CONSERVATION

There are several areas in which limitations in available materials or materials understanding will affect U.S. efforts in conserving fuel and scarce materials. The need to conserve fuel in industry, electricity generation, energy transmission, and transportation sectors provide incentive for materials research at elevated temperatures. It has been estimated,[8] for example, that the energy used in industrial processing, which consumes roughly 30% of the nation's energy, could be practicably reduced by as much as 1.5 quads per year (1.5×10^{15} Btu). This potential for energy conservation is significantly limited by a lack of suitable insulation at an acceptable cost. Fundamental studies of thermal insulation materials are necessary (1) to define heat transfer processes operative in insulations for various temperature ranges and atmospheres and (2) to investigate new microstructural/compositional systems to determine their insulation potential.

Another important potential for energy conservation in the industrial sector is heat recovery from combustion gases. Recovery of this energy would be most easily accomplished by using a recuperator or heat exchanger to transfer exhaust heat to the air used for combustion. Fuel savings of up to 25% could be realized in this way.[9] However, metallic recuperators are currently limited to $T_{max} \approx 900°C$, and the available alloys are expensive and easily degraded by medium- or low-grade fuels. New ceramic systems are needed for high temperature use up to 1650°C, and improved lower temperature alloys are necessary to allow accelerated industrial use of metallic recuperators.

The transportation sector, consuming about 25% of the U.S. fuel expenditure, is frequently limited by materials in efforts toward conservation. A recent study[10] on vehicular propulsion systems strongly emphasizes the fuel economy advantages of the Brayton and Stirling cycle engines (Fig. 2.3). These engines require ceramic materials for high temperature operation which do not exist today, although non-oxide ceramics hold

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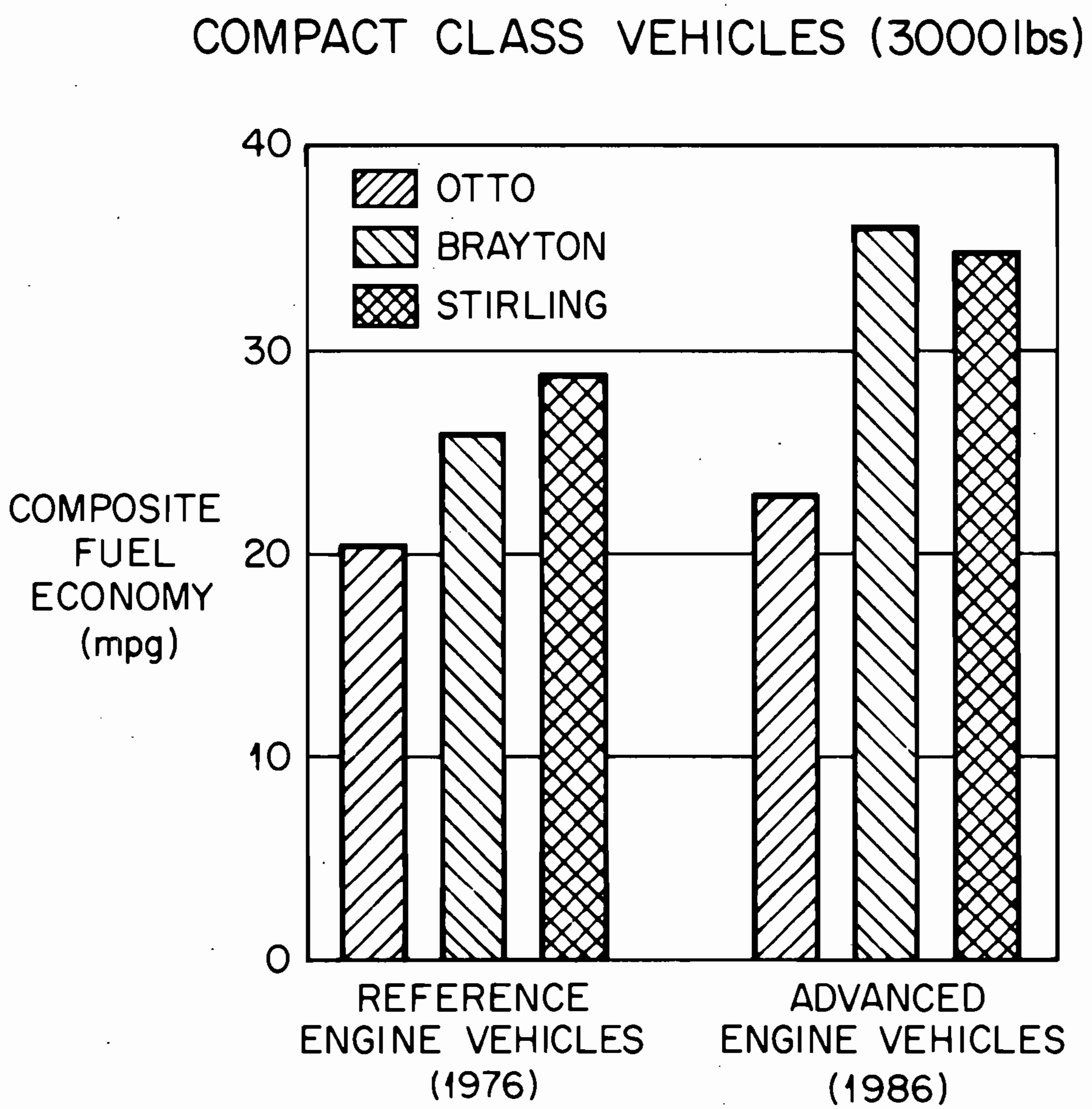

Fig. 2.3. Comparative efficiencies of present and advanced vehicular propulsion engines for 3000-pound vehicles. Source: Jet Propulsion Laboratory, *Should We Have a New Engine? Summary*, SP 399-vol. I, pp. 1-110; *Technical Reports*, SP 400-vol. II, pp. 1-560, Jet Propulsion Laboratory, Pasadena, Calif., 1976.

some promise of success. Advanced turbine and Stirling engines can only evolve through development of improved refractory ceramics. A key to this development is a fundamental understanding of materials synthesis and processing and their effects on microstructure. Previous support for work on these high performance ceramics has been cyclical and frequently governed by requirements for short-term payoff. A research environment capable of systematic and longer range studies is required.

Another increasingly important conservation-related topic is the restricted utilization of scarce, critical resources, many of which must be imported by the United States. Examples having direct bearing on the use of materials at elevated temperatures include chromium and cobalt. A significant fraction of chromium usage is for oxidation- and corrosion-resistant materials to operate at steam temperatures or higher. It is imperative that alternatives be developed for high chromium alloys or even for moderate alloy steels such as Fe–2-1/4 Cr–1 Mo. High reliability coating techniques (most of which are high temperature techniques) such as sputtering, physical or chemical vapor deposition, diffusion bonding, cladding, and weld overlaying require increased attention. [These suggestions and others may be found in a recent study of National Academy of Science (Ref. 11).] Underlying the viability of such alternate materials or coatings is the need for fundamental understanding of oxidation and corrosion processes at the elevated temperatures at which these materials will be used.

Although cobalt is used in some high temperature alloys, it is a primary component in the manufacture of cutting tools, mainly through its unique property of wetting tungsten carbide. A shortage of cobalt, therefore, will require an alternate binder (unlikely), a new processing technique for cutting tools, or new types of tool materials. Each of these alternatives will require studies in high temperature synthesis and processing of materials. It should be noted that the tips of cutting tools, per se, with operation conditions of high temperatures and stresses, present an example of the importance of studying high temperature erosion.

2.5 BROAD EXPLORATORY RESEARCH

The topics discussed in Sects. 2.1 through 2.4 are oriented chiefly toward existing technologies and temperatures no higher than 1500°C, and the research goals are evolutionary in nature. The exceptions cited have been in advanced energy systems such as MHD and fusion, for which significant breakthroughs in high temperature materials are required. Underlying such potential breakthroughs is the general need for understanding behavior of materials and phenomena at high temperatures — that is, the science of materials at temperatures greater than 1500°C.

To explore this area of materials science, known high temperature materials must be investigated and new materials must be prepared. The synthesis of such new materials requires sophisticated techniques that are generally not available. The preparation of single crystals of some of these materials, which will be necessary for the measurements of their physical properties, probably will require the development of new crystal growth techniques.

For systems to operate at significantly higher temperatures ($\gtrsim$ 1500°C) than present technology permits, alternative structural materials must be developed. It is already known that some materials such as ceramic oxides, carbides, and nitrides have some of the necessary properties for such use. Compounds are known that have melting points in excess of 2000°C and that are especially corrosion and erosion resistant. Research to improve their mechanical properties, so that they could be used as structural components, would have enormous technological impact.

The properties of materials at very high temperatures are so scarcely determined and poorly understood that phenomena in this temperature regime are yet to be defined. Many high temperature materials have very interesting electrical, optical, and magnetic properties at lower temperatures, but even properties of practical significance are not known with accuracy at high temperatures. For example, the conductivities of electrical insulators have not been established accurately. The mechanisms of charge transport or of electrical breakdown have not been established. While a detailed knowledge of the band structures of electrical insulators has not been required for applications to present technologies, insulators may be needed for application in some future energy system in which much higher temperature and voltage gradients may be encountered. Atomic transport in nonmetallic solids is also poorly understood. Except for the simplest ionic solids and the semiconductors, silicon and germanium, there is a paucity of precise diffusion data and verified theoretical models on which to base even first-approximation design calculations.

The ability to conduct systematic research on materials at very high temperatures holds the potential for the discovery of new properties of known materials and for the development of new classes of materials. Finally, new physical phenomena may be discovered which might allow entirely new energy systems to be invented. Such long-term research holds the possibility of contributing to the energy needs of the United States in a revolutionary way. There are many exciting possibilities for research in this major unexplored area of solid materials.

3. TECHNOLOGICAL PROBLEM AREAS REQUIRING RESEARCH SUPPORT ON MATERIALS AT ELEVATED TEMPERATURES

Technological problem areas requiring research support in elevated temperature materials are grouped by energy system in Table 3.1. Near-term energy systems of interest to ERDA/DOE are considered primarily, although some longer range systems have also been examined. It is clearly demonstrated that we are currently faced with technological problems whose origins lie in the degradation of materials by adverse environments and elevated temperatures. We lack essential ability to predict the behavior of many engineering materials and structures, and, as well, we lack the ability to use efficiently and effectively inherent material capabilities.

Problems are cited in temperature ranges partitioned in the following way: room temperature to 450°C, 450 to 850°C, 850 to 1250°C and >1250°C. The examples cited in each temperature range represent present or soon-to-be encountered problems. Thus, their solutions will frequently require development work, as well as underlying research. (Some of this research is outlined in Sect. 6.) Present work is confined to more conservative temperature regimes than should be advocated for a laboratory whose research leads technology. Even though we may expect a return for research at temperatures where technology now requires attention, a basic laboratory should also explore the forefront in elevated temperature behavior; i.e., it should emphasize the >1250°C range.

Table 3.1. Technological problem areas requiring research support in elevated temperature materials grouped by energy system

ENERGY SYSTEM	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
FOSSIL ENERGY					
1. Coal Liquefaction [Note: Some form of coal gasification will probably accompany liquefaction. Materials problems associated with the gasification step are listed under gasification.]	X	×*			erosion and corrosion of piping and valves
	X	×			hydrogen attack
	X	×			catalyst improvements
	X	×			stress corrosion cracking
	X	×			filter materials for removing ash
2. Coal Gasification	X	X			hydrogen attack
	X	X			synergistic effects of environment and mechanical stresses
	X	X			fracture mechanisms and crack growth rates
	X	X			structural and mechanical characterization of welds
	X	X			fatigue
	X	X			metal erosion of pipes and valves
	X	×			catalysts for methanation
			X	X	refractory corrosion and erosion
			X	X	refractories development
3. Direct Utilization of Coal	×	X			corrosion in the fireside environment
		X			synergistic effects of environment and mechanical stresses

*The symbol × indicates that the problem areas extend only slightly into the marked temperature regime.

Table 3.1. (continued)

ENERGY SYSTEM	R.T. – 450°C (R.T. – 850°F)	450 – 850°C (850 – 1550°F)	850 – 1250°C (1550 – 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
		X			creep and creep-fatigue characterization of boiler materials
	X	x			crack initiation and growth in steam turbine materials
	X	x			oxidation and exfoliation of steam side tubes
	X	X			erosion
		X			sorbent chemistry and structural behavior
4. Advanced Direct Utilization of Coal		X	X		fire-side corrosion
		X	X		synergistic effects of environment on mechanical properties
		X			creep, creep rupture and creep-fatigue of boiler materials, especially for pressurized systems
		X			alkali metal/boiler tube interaction
			X		advanced alloys and coatings development
			X	X	refractory corrosion and erosion
Turbomachinery [Note: These areas may also be applicable to advanced gas-fired turbine designs.]			X		erosion/corrosion of turbine blades
			X	X	Si_3N_4, SiC processing, fabrication and mechanical characterization
			X	X	non-oxide ceramic development
		X	X	X	fracture of brittle materials
			X	x	composites, dispersion strengthened materials, directionally solidified eutectics, long-range ordered alloys
			X	x	creep and creep-fatigue characterization for advanced materials

Table 3.1. (continued)

ENERGY SYSTEM	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
5. Magnetohydrodynamics				X	erosion/corrosion of MHD channel
				X	slag-seed corrosion of MHD electrodes
				X	development of ceramic electrodes
				X	thermal stress/shock in refractory materials
				X	thermal and electrical stability of electrode materials
				X	electrical conductivity in ceramic materials

Table 3.1. (continued)

ENERGY SYSTEM	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
6. Fuel Cells		X	X		physical and electrical properties and structural stability of solid electolytes
		X	X		cathode-electrolyte interaction
		X	X		coating technology
		X			molten carbonate-electrode interaction
	X				low cost catalysts
NUCLEAR ENERGY					
1. Light Water Reactors	X	×			stress corrosion cracking
	X				mechanical characterization of textured cladding
2. HTGR		X			steam generator materials and welds
[Note: These materials technology areas, excepting fuels development, are applicable to the GCFR or VHTR concepts]			X		carbon-based fuel stability
		×	X		superalloy development for the impure He environment
		×	X		advanced materials such as Mo-base alloys, directionally solidified eutectics, long-range ordered alloys, composites, dispersion strengthened alloys
3. LMFBR	X	X			steam generator alloy development
	X	X			mechanical design procedure for complex elastic/inelastic structures
	X	X			rigorous mechanical characterization of structural materials and welds
	X	X			long term extrapolation of failure criteria

Table 3.1. (continued)

ENERGY SYSTEM	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
	X	X			structural stability and mechanical properties of fuel cladding and duct materials during irradiation
		X	X	X	fuel characterization
		X	X	X	advanced fuels
FUSION ENERGY					
1. MFE	X	x			sputtering of coated stainless steel
	X	X			refractory alloy stability and mechanical properties before, during and after irradiation
	X	X			stainless steel and refractory alloy compatibility with Li, Li-salts and other coolants
			X	X	limiter and probe materials, filaments for neutral beam injectors
2. Laser Fusion	X	X			fatigue and crack growth in containment materials
	X	X			structural material compatibility with coolants
	X	X			structural stability and mechanical properties during irradiation
	X	X			tritium handling
	X	X	X	X	optical properties and physical properties of glass
SOLAR AND GEOTHERMAL ENERGY					
1. Solar Heating	X				improved polymer strength
2. Photovaltaics			X	X	crystal growth
			X	X	Si grain growth
				X	Si ribbon growth
		X	X	X	coating techniques

Table 3.1. (continued)

ENERGY SYSTEM	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
3. Solar-Thermal Conversion	X	X			optical and mechanical properties of high absorption coatings
	X	X			thermal shock and fatigue
4. Geothermal	X				stress corrosion cracking
	X				develop low-cost alloys having specific corrosion resistance
	X				scale suppression on carbon steel
	X	X	X		drill bit longevity
ENERGY CONVERSION, STORAGE AND TRANSMISSION					
1. Brayton Cycle, Stirling Engines			X	×	ceramics for structural engine components, recuperators, and regenerators
			X	X	SiC, Si_3N_4 processing, fabrication, and mechanical characterization
		X	X		interaction of superalloys with impure inert gas
		×	X		advanced turbine materials such as Mo-base alloys, long-range ordered alloys,
2. Thermionic Topping Cycle			X		electrical, physical and mechanical properties of collectors
3. Batteries	X	×			corrosion and electrode degradation in Li-molten salt, Li-S and Na-S systems
	X	×			improved conductivity in solid electrolytes - materials processing
	X	×			alternate current collectors, separator materials

Table 3.1. (continued)

ENERGY SYSTEM: ENERGY CONSERVATION	R.T. - 450°C (R.T. - 850°F)	450 - 850°C (850 - 1550°F)	850 - 1250°C (1550 - 2250°F)	>1250°C (>2250°F)	Technological problem areas requiring research support on materials at elevated temperatures
1. Thermal Insulation		X	X	X	thermal and physical properties of ceramics
		X	X	X	thermal shock and fatigue
		X	X	X	ceramic development
2. Alternate Alloys	X	X			low chromium alloy development
	X	X	X	X	coating improvements
3. Aluminum Smelting		X			improved electrode materials

4. NEED FOR A HIGH TEMPERATURE MATERIALS LABORATORY

It has been demonstrated in Sects. 2 and 3 that strong incentives do exist for research on materials at elevated temperatures based directly on the technology needs of our energy systems. Neither private industry nor another government agency is likely to fund the basic research needed to support these energy system materials needs. A comprehensive, ERDA/DOE-supported laboratory appears thus to be the most effective medium- to long-range approach to solve the deficiencies that now exist. There exists no single U.S. laboratory with the extensive facilities and expertise that are proposed for HTML. This point will be addressed in Sect. 5, along with a brief examination of foreign laboratories dedicated to elevated temperature materials studies.

Section 4 points out the advantages of a large, centralized laboratory such as HTML, having interdisciplinary research capabilities. Emphasis is placed on the concept that *an ERDA/DOE-dedicated laboratory, with its specialized equipment and personnel, would serve as an important national resource.* Those factors favoring an HTML are listed below in abbreviated form. They are then expanded for individual consideration. These factors include:

1. An HTML with its large staff of professionals from several disciplines would be capable of addressing broad, multifaceted or multidisciplinary questions.
2. An HTML would improve the resolution and detection of high temperature materials phenomena through the development of uniform procedures for preparing, analyzing, and testing materials.
3. An HTML would serve as an ERDA/DOE resource, housing equipment and expertise in the specialized area of high temperature materials synthesis.
4. An HTML would serve as an ERDA/DOE resource capable of performing difficult property measurements at high temperatures.

5. An HTML would be able to respond in a coordinated fashion to a problem in the use of materials at elevated temperatures requiring immediate attention and understanding.
6. An HTML would be able to attack the problem of predicting long-term (10 to 30 years) service behavior from short-term tests by housing the needed long-term, carefully controlled experiments.
7. An HTML would provide a center for broad exploratory research on matter at high temperatures (>2000°C), a regime that is relatively unexplored.

4.1 MULTIDISCIPLINARY RESEARCH

HTML, with its large staff of professionals from several disciplines, would be capable of addressing broad, multifaceted or multidisciplinary questions. An example of such an elevated temperature materials problem whose scope exceeds the comprehension and exploration capabilities of a single researcher or a small group of researchers is the micromechanical justification of a mechanical equation of state. It is a formidable, fundamental problem that has direct impact on energy systems and that will require massive, multidisciplinary research efforts for solution. A system of equations that describes the inelastic behavior of solids at elevated temperatures in terms of state variables has become an established objective of many researchers in the field of mechanics of materials. The incentive is that the expensive efforts required to accumulate mechanical data on a given alloy for a given system design (e.g., 316 stainless steel for use in an LMFBR), may be minimized through the accepted generalizability of a mechanical equation of state. The objective extends beyond the normally simplified equations that describe mechanical deformation under static conditions; it is proposed that a system of state variables be developed which allows the prediction of instantaneous deformation under any loading conditions at any temperature.

One major approach, that of Hart and coworkers,[12,13] has been directed mainly toward the incorporation of important macroscopic phenomena (e.g., strain hardening, Bauschinger effect, recovery, anelastic strain, etc.) into a rheological model, where various components of the model are described mathematically in terms of state variables. This model has evolved to the point that it is consistent with significant amounts of experimental data, gathered mainly through uniaxial stress-relaxation experiments. The most recent extension of the work has been toward the accommodation of micromechanical deformation mechanisms that have been discovered over the last several decades, (e.g., grain-boundary sliding, dislocation glide and climb processes as governed by microstructural features). This phase is perhaps the most important in attaining the overall objective, since we have begun to understand the microscopic behavior and now know where various limitations exist in the numerical approaches toward modeling macroscopic behavior.

The link between our understanding of defect interactions and a manageable, comprehensive model of material behavior is a long-range research goal. It is not a problem within the near-term grasp of any small research group. Another aspect of the problem which must be explored is the thermodynamic meanings of those quantities given the status of state variables; i.e., are these variables unique, do they behave as state variables, and do they describe sufficiently all possible states of a material?

This problem encompasses widely separated disciplines. A group capable of considering the entire problem of a mechanical equation of state would need to contain researchers in the fields of solid mechanics (both theoretical and experimental), metallurgy and solid state physics, along with computational and experimental support personnel. It is the kind of research problem in elevated temperature materials behavior which would be quite suitable for an interdisciplinary laboratory such as HTML.

4.2 EXPERIMENTAL RESOLUTION

An HTML would improve the resolution and detection of high temperature materials phenomena through the development of uniform procedures for preparing, analyzing, and testing materials. Improved resolution means, in this case, that undesirable data scatter can be reduced to the point that small variations in properties become meaningful and reproducible. Small variations of this sort can have drastic effects on the measured properties for materials which are nominally the same. Fig. 4.1 shows that the small heat-to-heat variations in the composition/structure of 304 stainless steel result in major changes in the time to rupture.[14]

All of the steps from material synthesis to data analysis involve procedures that are frequently considered too time-consuming or too pedantic to record. The interlaboratory differences in experimental results, which may arise from this lack of documentation (and from more standard sources of error), may be so large as to inhibit understanding of the phenomenon being studied. Figure 4.2 gives one such example in which the high temperature electrical conductivity of Al^2O^3 was measured in seven separate investigations.[15] The results are shown to differ by as much as five orders of magnitude. These investigations were done on one of the most common and important ceramic insulation materials presently used! One would have a difficult time in understanding the conduction processes, and furthermore, one would be at a loss for reasonable design information. Other, similar examples may be found for thermal conductivity measurements.[8] Here, the difficulties increase significantly with increases in temperature. The practical repercussions of such measurement uncertainties can be quite large; for example, the power ratings of fission reactors are very sensitive to the value of thermal conductivity of UO_2 used for the overall safety analysis.[16]

There is a special need for the development of reliable measurement techniques at temperatures in excess of 1500°C. An institute such as HTML would be sufficiently large and stable to develop such standardized techniques, and thus the probability of success in this area would be improved.

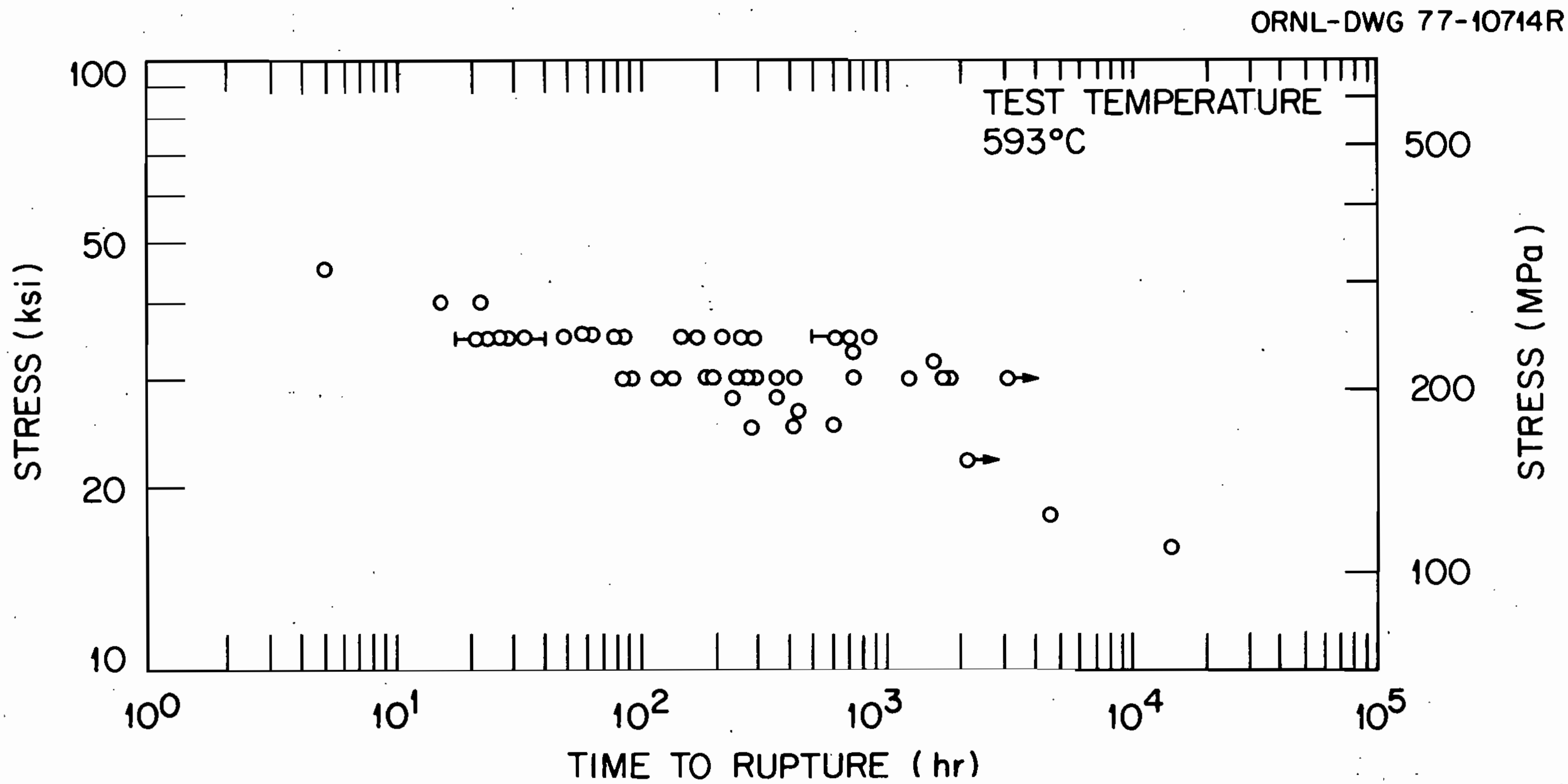

Fig. 4.1. Comparison of stress rupture results at 593°C for 20 different heats of 304 stainless steel. Source: After V. K. Sikka et al., "Heat-to-Heat Variation in Creep Properties of Types 304 and 316 Stainless Steels," *Trans. ASME* 87: 243–251 (1975).

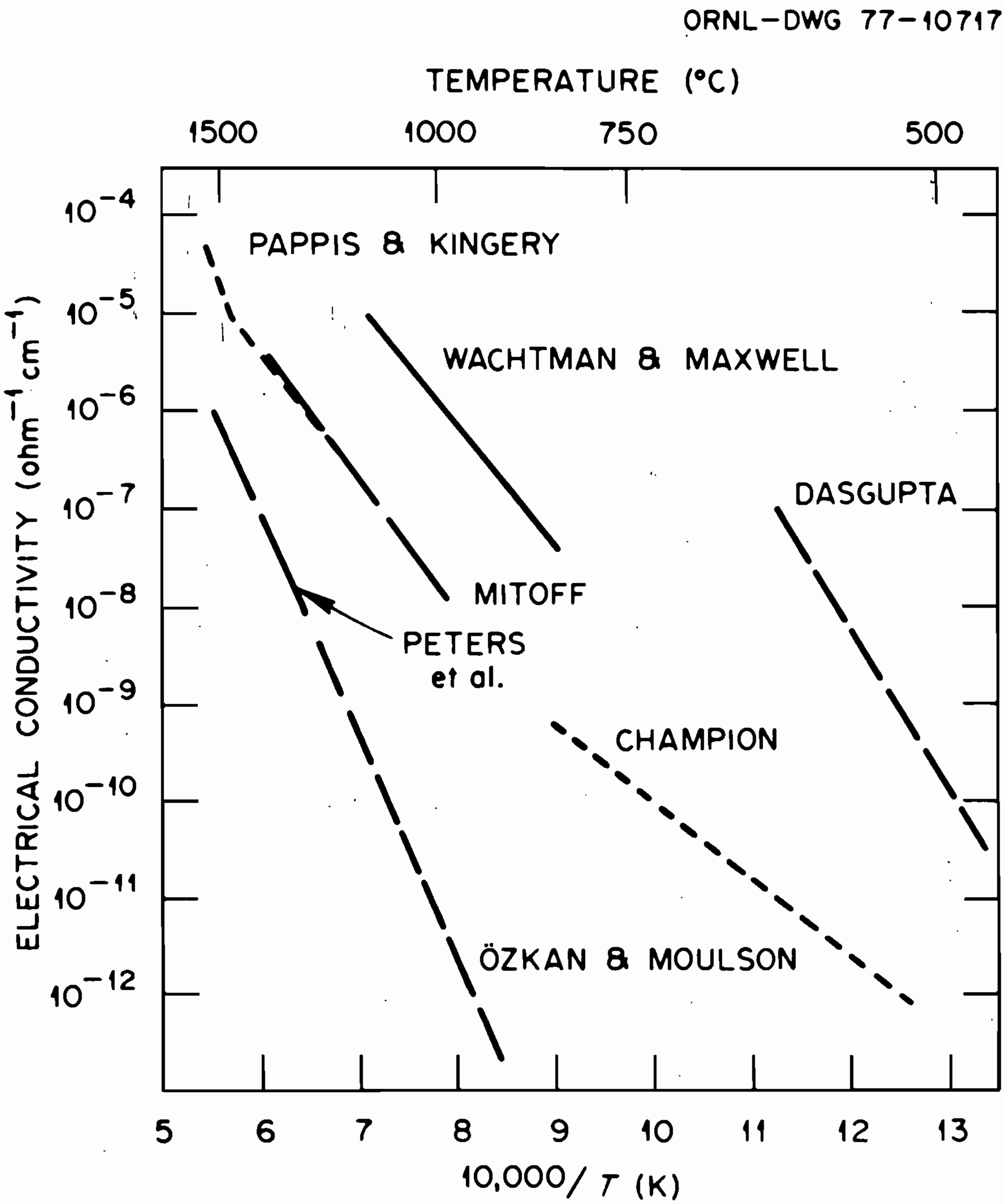

Fig. 4.2. Reported values for the electrical conductivity of Al_2O_3. Source: After P. Kofstad, *Nonstoichiometry, Diffusion and Electrical Conductivity in Binary Metal Oxides*, J. Wiley and Sons, New York, 1972, p. 344.

4.3 SYNTHESIS FACILITIES

An HTML would serve as an ERDA resource, housing equipment and expertise in the specialized area of high temperature materials synthesis. Many avenues of research have been impeded by the availability of test materials, many of which require high temperature techniques for synthesis and processing. These techniques include zone refining and crystal growth, physical and chemical vapor deposition, hot-pressing and sintering, casting, and hot-working. An established laboratory facility having the breadth of skills covering these areas, with particular emphasis on high temperature materials, would be a valuable resource for ERDA. Such a facility would emphasize the continuous evolution of synthesis techniques, while maintaining a stable laboratory capable of producing standardized materials, such as materials having well-characterized stoichiometry. An important part of this activity is the structural characterization of new materials using techniques such as x-ray, electron and neutron scattering, and electron and optical microscopy.

Special equipment will be necessary for developing suitable environments for the synthesis of materials having melting points in excess of 3000°C. Along with the development of new techniques, an HTML could provide many services that are similar to those done by the Research Materials Program at ORNL.[17] Needed materials could be identified. Information on the availability, preparation, and properties of high temperature materials could be provided. Research-quality specimens of materials that are not commercially available could be supplied for both internal and external research efforts of interest to ERDA/DOE.

4.4 PROPERTY MEASUREMENT FACILITIES

An HTML would serve as an ERDA resource capable of performing difficult property measurements at high temperatures. Data on the thermal, physical, electrical, and optical properties of materials at high temperature are usually unreliable or scarce because the measurements are inherently difficult. However, they may be quite necessary because low-temperature properties often are not valid when extrapolated to high temperatures. Such data are important because they form the basis for the selection of materials for a given application. An HTML would develop new techniques that are based on state-of-the-art technology for the measurement of materials properties.

Properties measurements are especially valuable when coupled with materials synthesis. They serve as the basis for the characterization of materials in terms of the effects of impurities, composition, and structure on the properties. Such coordinated efforts are necessary to distinguish between the intrinsic and extrinsic contributions to high temperature phenomena. Moreover, advances in the theory of materials have improved our understanding of the relationships between the various material properties. Thus, it is probable that properties measurements may reveal new high temperature phenomena.

The status of electrical conductivity data for insulators gives a good illustration of the need for high temperature data. Magnesium oxide is widely used as an electrical insulator and is proposed, for example, for MHD channels, even though no conductivity data exists for temperatures above 1650°C. Moreover, the mechanisms responsible for electrical conduction and breakdown are virtually unknown. The influence of impurities, extended defects, and grain boundaries have not been determined.

4.5 RESPONSIVENESS TO ERDA/DOE NEEDS

An HTML would be able to respond in a coordinated fashion to a problem in the use of materials at elevated temperatures requiring immediate attention and understanding. It may be predicted, with the increasing number and variety of elevated temperature energy systems, that a high temperature materials problem may be encountered that requires a rapid solution. An analogy may be drawn between this hypothetical problem and the recently encountered phenomenon of neutron radiation-induced swelling.

The point being advocated here is that for a problem requiring fundamental investigation and solution in the area of elevated temperature materials behavior, there would exist in an HTML the assembled scientific force capable of solving such a problem. There would be a reduced response time necessary for research to be initiated. It may also be true that the likelihood of so suddenly encountering a major new problem in high temperature materials analogous to swelling will be reduced by the very existence of an HTML.

4.6 LONG-TERM EXPERIMENTAL CAPABILITIES

An HTML would be able to attack the problem of predicting long-term (10 to 30 years) service behavior from short-term tests by housing the needed long-term, carefully controlled experiments. As was mentioned earlier in Sect. 2.2, there are practical difficulties in extrapolating, for long-term application, the results obtained in short-term experiments. Deformation and failure mechanisms may show important differences for experiments differing significantly in duration. Structural kinetics data from short-term experiments may not apply to long-term situations. Normally these deficiencies may arise when performing experiments at several temperatures, then extrapolating, based on the temperature dependence of the observed process, to obtain the rate for this process at a different temperature (Fig. 4.3). An example of invalid predictions of precipitation reactions based on short-term experiments has been recently disclosed in the study of a 17-year-old (150,000-hr) superheater component made of 321 stainless steel.[18] Extrapolations of the current time-temperature-transformation (TTT) curves developed from tests up to 4000 hr long predict the evolution of TiC, $M_{23}C_6$ and, possibly, chi phase; but this is not the case. Actual examination showed TiC, sigma phase, and three other phases, two of which had not been observed previously.

It is normally difficult to acquire funding for or to convince personnel to perform experiments lasting years; this is doubly true in institutions with unstable funding and rapid personnel turnover. For example, the

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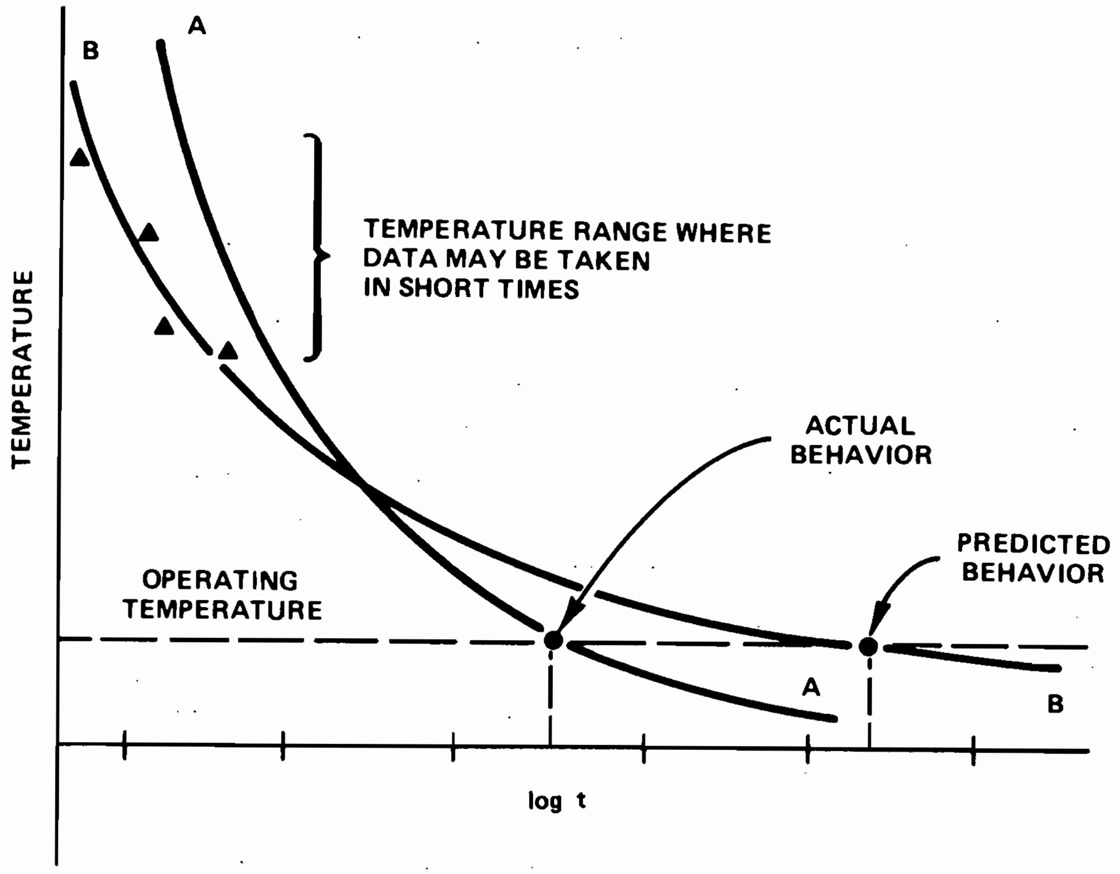


t = TIME FOR THE COMPLETION
OF A STRUCTURAL CHANGE,
THROUGH MECHANISM A OR B

(A AND B ARE COMPETING MECHANISMS)

Fig. 4.3. It may be injudicious to extrapolate short-term data for long-term applications. In this case the transformation or structural change occurs by mechanism B at temperatures where measurements may be made, but by mechanism A under operating conditions.

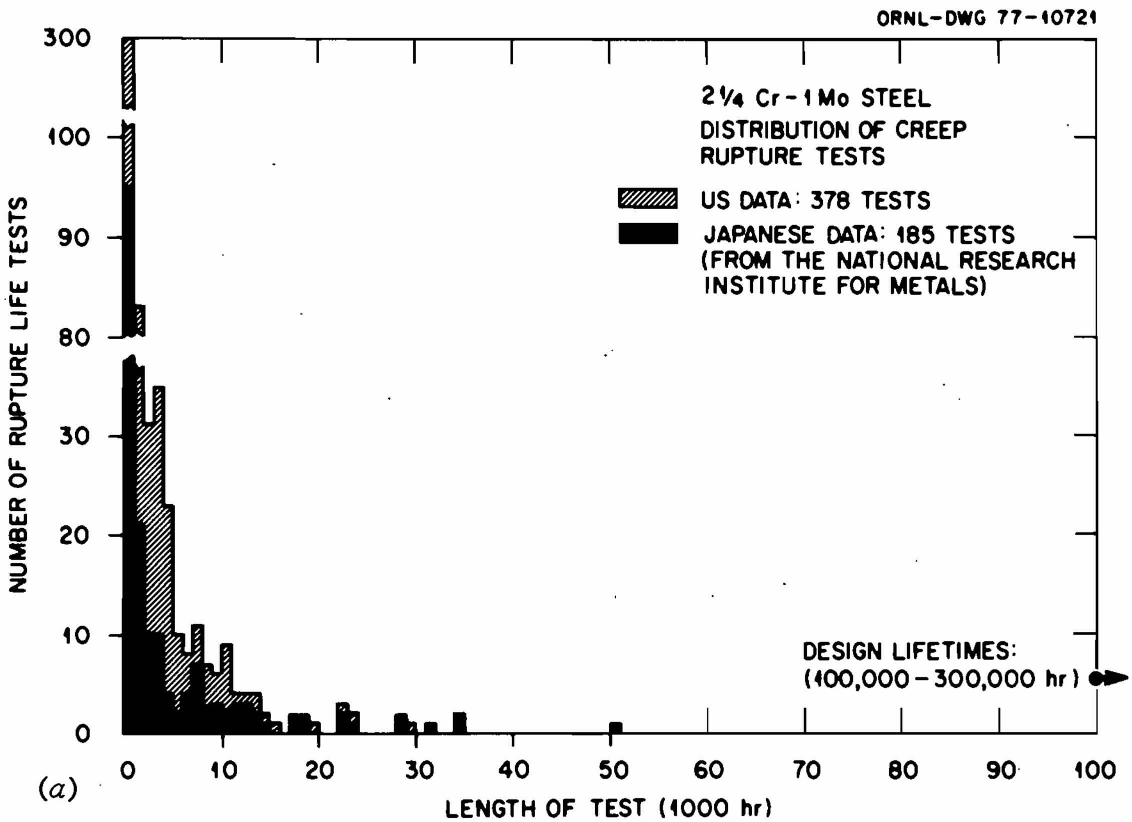
reported creep tests for the alloy, Fe-2-1/4Cr-1 Mo,[19] and fatigue tests for 304 stainless steel,[20] important structural alloys, are shown in Fig. 4.4. Here we see that very few tests are performed for lengths of time even approaching design life. The primary impediment is the allocation of appreciable equipment and space for such experiments lasting about 100,000 hr. High cycle fatigue tests or fatigue tests with extended hold periods are impeded further by the relatively expensive equipment required. An institute such as HTML would be large enough to make a commitment of some of its facilities toward experiments that would allow *realistic* evaluations of material behavior at elevated temperature. These would include long-term mechanical and structural investigations.

4.7 CENTER OF HIGH TEMPERATURE SCIENCE

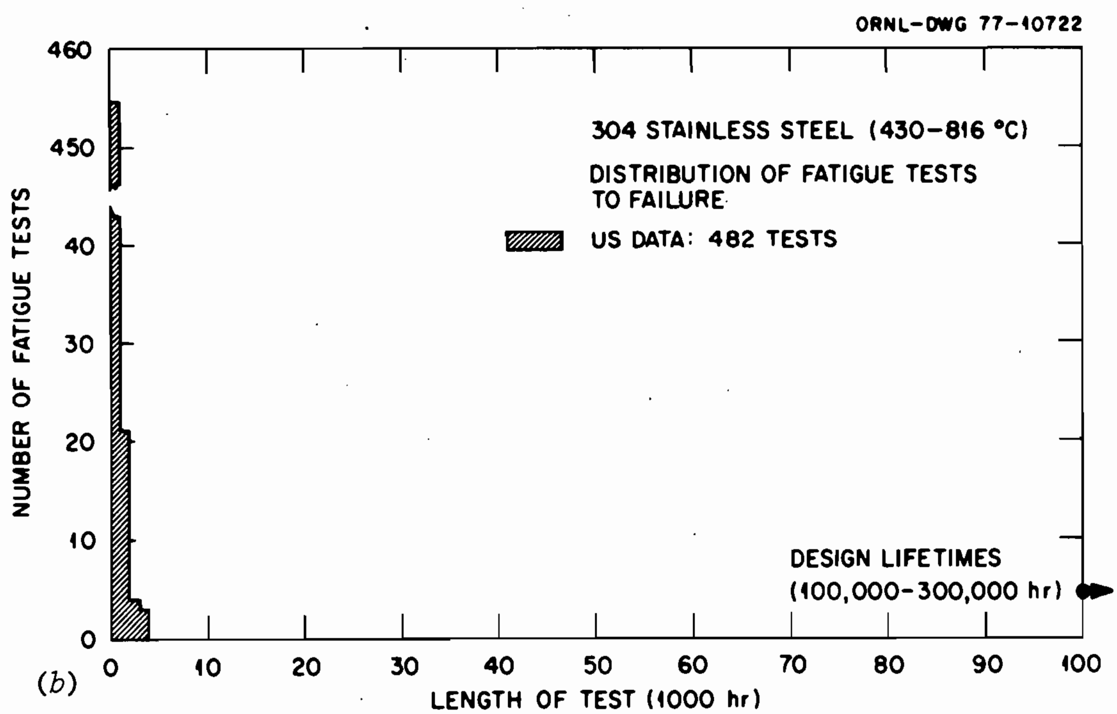
An HTML would provide a center for broad exploratory research on matter at high temperatures (>2000°C), a regime that is relatively unexplored. The resources cited in Sects. 4.3 and 4.4 would allow for basic studies of many properties in temperature regimes that have hardly been explored. It is reasonable to expect that new phenomena will be uncovered in certain areas of mechanical, physical, and chemical behavior. The study of such phenomena should help elucidate the mechanisms controlling them and thus specify the material variables that can be altered to obtain desired properties.

As an example, the melting point is one of the fundamental properties of materials at high temperatures and yet one which is still poorly understood from a basic point of view. An understanding of the phenomenon of melting would greatly improve our knowledge of the behavior of high temperature materials and might lead to the development of materials with higher melting points.

In order to explore the regime of very high temperatures (>2000°C), it may be necessary to develop a whole new array of experimental tools or to modify the tools now available, to provide the capability of probing



(*a*)



(*b*)

Fig. 4.4.(*a*) Creep rupture tests for Fe-2-1/4Cr-1Mo to date. Source: T. Hebble and C. R. Brinkman, unpublished. (*b*) Fatigue tests for 304 stainless steel. Source: D. R. Diercks and D. T. Raske, *Elevated Temperature Strain-Controlled Fatigue Data on Type 304 Stainless Steel: A Compilation Multiple Linear Regression Model, and Statistical Analysis*, ANL-76-95, December 1976.

the physical properties of materials at these temperatures. Many of the probes now available to experimentalists in the area of materials science have been designed to provide the most information at low temperatures at which the thermal vibrations of the solid are relatively unimportant. In order to disentangle optical and electronic effects from the vibrational effects at high temperatures, it may be necessary to develop ultra-short time resolved optical spectroscopy, for example.

5. OAK RIDGE NATIONAL LABORATORY AS A SITE FOR HTML

In this section we address two questions: (1) Is there now in existence in the United States a laboratory or research institute that carries out the program envisioned for HTML, or is there an institute that with only minor additions and changes can meet these requirements? (2) What are the specific reasons for proposing that the Oak Ridge National Laboratory is a suitable site for a high temperature institute?

5.1 EXISTING RESEARCH FACILITIES

To meet the specifications set out in Sect. 4, a high temperature laboratory should meet the following criteria:

1. It should have a strong and basic materials science program in the areas of high temperature materials.
2. It should have companion programs that extend from basic and applied research to engineering development related to the ERDA/DOE missions.
3. The institute should have a tradition of interacting with universities, industries, and other research laboratories.

In the light of these criteria we have examined industrial laboratories, nonprofit research institutions, university research centers, Federal contract research centers, and Federal government laboratories. In each category there are outstanding institutions where multidisciplinary work is in progress on problems related to elevated temperature materials science and engineering. We have not found any single institution, however, that can be regarded as an equivalent to HTML, nor have we found one that with minor alterations can be converted. In general, industrial laboratories direct their work narrowly to the needs of the industry, and no industrial laboratories currently exist that have the broad-based expertise in basic materials science, which is a key ingredient of HTML. Industrial high temperature laboratories are connected mainly with the space and aircraft industries and do not have a tradition of broad energy-related research. Nonprofit research centers generally are institutions that do contract work and are not in the habit of doing long-range research. These institutions lack a connection with the ERDA/DOE mission, and in particular, they do not carry out the heavy engineering development that is expected to cross-fertilize the HTML research programs. Several universities have strong materials research centers, and the possibility exists that by adding high temperature programs to a number of them, one could obtain a research capability equivalent to HTML, albeit scattered among several institutions. The drawback in this scheme is again a weak coupling to the ERDA/DOE technology development. Although fragmentation of the program is undesirable, it is compensated to some extent by the existence of competing centers. To our knowledge no Federal government laboratory exists that meets the HTML criteria. The contract research centers such as Ames, Argonne, Brookhaven, Hanford, etc., do conduct high temperature materials research, but none of these contain a center with the breadth and devotion to high temperature problems that characterize HTML, (see, e.g., Ref. 21-25).

We therefore conclude that the establishment of HTML would not duplicate any existing research institution in this country — industrial, private, university or government — and that there are in fact no candidates for easy conversion to the HTML mission. HTML has to be established from the ground up. Its facilities and program plan must assure a broad attack on the high temperature problems relevant to the ERDA/DOE mission. Along with the long-range basic program, it must also function as a center of research and development in energy technologies that can be applied in a short time frame.

There is substantial, but diverse research in high temperature materials in western European laboratories.[23-25] There is significant work in high temperature thermodynamics at the National Physical Laboratory, England, along with some mechanical properties work which is also done at the Central Electricity Generating Board Laboratories, England. There are several research groups devoted to high temperature research in France such as the Centres des Recherches sur la Physique des Haute Temperatures, which is part of the University of Orléans, and the

Laboratoire des Hautes Temperatures, attached to the University of Paris. Part of the research carried out at Battelle Institute in Geneva, Switzerland, is devoted to high temperature materials. Research on high temperature materials is scattered throughout a number of German universities, research institutes, and laboratories.

The U.S.S.R. has several laboratories involved with high temperature materials. The Institute for High Temperature of the U.S.S.R. Academy of Sciences, Moscow, has strong programs in the thermodynamic and physical properties of materials up to temperatures around 3000°C. The A. A. Baikov Institute of Metallurgy, Moscow, conducts research on the synthesis of high temperature materials and on their physical and mechanical properties.

However, none of the European laboratories, to our knowledge, have the breadth or scope envisaged for HTML in the field of high temperature materials. The foreign laboratory that approximates the HTML concept is the National Research Institute for Metals (NRIM) in Japan. This Laboratory performs research in the fields of materials science, metallurgical behavior, process metallurgy, and metal processing. Approximately 230 professionals staff the Institute, which emphasizes materials research in both basic and applied areas. Extensive equipment for high temperature studies are available; for example, it houses 1100 creep apparata. (This is a greater number of machines than the combined total from the three U.S. laboratories having the largest number of creep machines.) Although its efforts in ceramics studies are considerably less than the level envisioned for HTML, the NRIM does perform very broad investigations of materials behavior at elevated temperatures.

5.2 THE OAK RIDGE SITE

By planning HTML at Oak Ridge National Laboratory, one reaps the fruits of extensive ongoing materials research. A strong basic materials science program exists at ORNL, and the expertise in high temperature technology extends over many years of work in many areas. Scientists from these materials programs will serve as the core staff of HTML and will assure that the new laboratory is productive and that its work is of a high quality from the very beginning.

Other factors to be considered include the following:

1. It is a fundamental policy of the Laboratory to encourage interaction with universities, to provide facilities for visiting research scientists whether from universities or from other laboratories, and to encourage exchanges with industry. There are special programs at the Laboratory concerned with the dissemination of new discoveries to industry and transfer of data, techniques, and processes to the industrial sector.
2. The ORNL staff has acted in many national and international organizations that are concerned with materials behavior. In the applied area it is active in bodies that deal with material codes and standards, with organizations that sponsor research, and with publications that disseminate and codify information; 20 technical information centers such as that for the Research Materials Program are active at ORNL.
3. ORNL provides the supporting and logistic services of a large laboratory including computer facilities and services, engineering design services, analytical chemistry, light and heavy particle bombardment capabilities, machine shops, and information services.
4. By locating HTML at Oak Ridge National Laboratory, a close geographic proximity to large energy development ventures would be assured. The interaction between the energy development programs and the HTML research programs is to be considered a two-way street. The problems encountered by the development programs would no doubt influence some of the research programs at HTML, and conversely the high temperature expertise and the high temperature research equipment of HTML would assure that engineering development programs avail themselves of the latest knowledge in the more modern high temperature facilities.

There are at least four divisions at ORNL that would contribute personnel and expertise to the areas central to HTML. The number of professionals in these four divisions, along with their disciplines, is provided in Table 5.1. All four divisions are engaged to varying degrees in basic materials research. Similarly, all four divisions have some portion of their effort directed toward high temperature applied science and technology.

With respect to proven expertise in the area of high temperature materials technology, the staff at ORNL has been involved in many significant high temperature materials technology programs since the late 1940s. It would be a difficult task to describe in any detail the scope and the accomplishments of these activities. Much of this work has been in support of applied technology programs. Some topical high temperature programs that have involved personnel at ORNL are shown in Fig. 5.1. Systems have been studied in which the operating temperatures for materials have ranged from 450°C (Liquid Metal Fast Breeder Reactor) to as high as 1800°C (Thermionics for Space Electric Power). In nearly all cases the materials research effort has involved most of the areas listed, for example, in Table 5.3.

A brief list of the ORNL achievements in one of the more basic areas of elevated temperature materials research, that of materials synthesis and preparation, is given in Table 5.2.

Table 5.1. Description of the technical staff at ORNL from which the staff nucleus for HTML could be drawn

	Division			
Personnel	Metals and Ceramics	Solid State	Chemistry	Engineering Technology
Total professionals	150	65	87	143
Basic (%)	30	70	70	25
Applied (%)	70	30	30	75
Chemists	22	6	77	4
Physicists	19	56	9	8
Metallurgists	78	3		1
Ceramists	17	0		
Engineers	14		1	130
Involved in high temperature science and technology (%)	40	15	10	40

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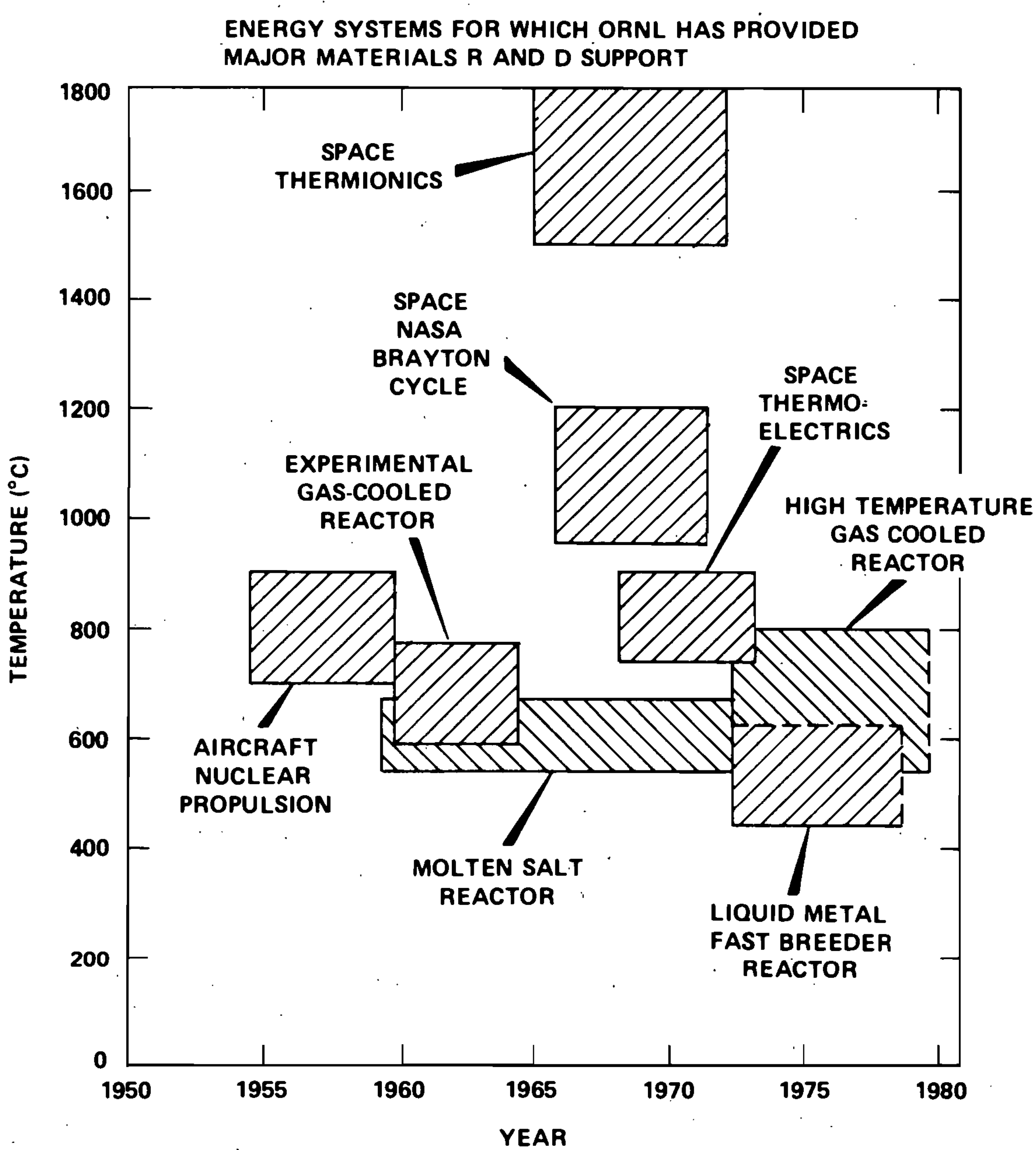

Fig. 5.1. Oak Ridge Natinal Laboratory involvement in energy systems requiring elevated temperature materials research and development.

Table 5.2. Selected work on the synthesis and preparation of elevated temperature materials at ORNL from 1960 to 1977

1. High-quality metal single crystals including Nb, V, Zr, Mo, and Re (by electron beam float zone melting), Cu, and rare earth metals have been grown and studied. (to 3300 K)

2. Several ionic crystals including KCl and isotopically enriched LiF have been grown. (600–1000 K)

3. Complex ferrite crystals and ultrahigh purity germanium crystals have been produced. (1400–1800 K)

4. The technique of reduction-distillation has been developed to prepare high-purity rare earth elements including Pr, Nd, Pm, Sm, Eu, Gd, Dy, Er, and Yb. (1400–2300 K)

5. At least 30 different metal oxide crystals have been grown from high temperature molten salts, e.g., ZrO_2, BeO, THO_2. Many of these have been doped with transuranic isotopes. (to 1800 K)

6. Several simple and complex oxides have been grown by flame-fusion (Verneuil). (to 2800 K)

7. Very high quality quartz, SiO_2, and eight other crystals have been grown hydrothermally. (to 900 K)

8. The technique of internal zone growth for directionally solidifying high temperature oxides and metal oxide-metal eutectics was discovered. (to 3100 K)

9. The new class of eutectics, metal oxide–metal binary and ternary systems, was discovered. About 40 binary systems have been found at ORNL or with a subcontracting laboratory, and eight ternary systems have been confirmed. (to 3000 K)

10. For edge-defined film-fed growth, a crystal growth method, we have investigated heat flow effects and boundary layer composition effects using eutectic oxides for direct interpretation. (to 2500 K)

11. ORNL has demonstrated expertise in the preparation of high-purity, thin film coatings or free-standing foils for targets for accelerator studies, using vapor desposition, sputtering chemical vapor deposition, and other sophisticated techniques. (to 2800 K)

12. Levitation casting of small quantities of pure materials has been used successfully.

13. Metal processing work on W-Re, W-THO_2, Ir, and other high temperature alloys is done routinely. (to 2200 K)

Table 5.2 (continued)

14.	The high temperature, one-step production of UO_2 from UF_6 was prefected. (to 1400 K)
15.	Patents are held in the CVD processing of W and B_4C.
16.	Carbides and nitrides of Hf and the actinides have been synthesized and processed extensively.
17.	Electron beam guns currently used for melting materials were developed.
18.	High temperature ordered alloys have been prepared. (to 2400 K)
19.	High-density ceramics, including EuB_6 and other borides, Eu_2O_3-W cermets, and other ceramics have been synthesized. (to 1900 K)
20.	We have developed the chemical vapor deposition of cubic SiC of near theoretical density and determined the stacking fault and dislocation structures as a function of the deposition conditions. (1300–1600 K)
21.	Deposition conditions were determined for the production of bulk isotropic pyrocarbons from various hydrocarbon gases. (1500–1600 K)
22.	Fabrication methods for producing complex ceramic shapes were developed. (to 2500 K)
23.	Highly thermally shock-resistant graphite has been prepared and studied. (to 2300 K)
24.	Several high-purity transparent oxide crystals have been grown, including MgO, SrO, and CaO. (to 3000 K)

In addition to possessing a strong basic materials science program with proven expertise in the area of high temperature materials technology, ORNL has strong applied and engineering programs directed toward the ERDA/DOE mission. In this respect, ORNL currently houses about $9 million devoted to elevated temperature materials behavior (FY 1977 operating funding). The breakdown by selected research topics is shown in Table 5.3 and in Fig. 5.2. Note that the majority of this work ($6 million) is sponsored by applied research programs. That most of this funding is associated with projects that may not, for the most part, be suitable for direct inclusion into HTML does not detract from the considerable expertise that exists at ORNL. Some of these projects would be modified for inclusion into HTML, while others would provide a basis for expansion, as indicated in Sect. 6. For example, the large ($3.5 million) applied mechanical properties and high temperature structural behavior programs would provide an excellent foundation for fundamental research in the areas of deformation, failure, and mechanical modeling. We would maintain, at the same time, our ability to interact and influence the applied research in progress. Other areas of high temperature materials research offer similar opportunities for interaction between basic and applied research, and a laboratory such as HTML will provide the fertile soil in which such interactions can flourish.

In summary: ORNL has a strong materials research program that can serve as a nucleus for the new HTML, it has the supporting structure for broad research, and it has the required coupling to the ERDA/DOE technologies. The need now is for a unified laboratory with new and enhanced capability to achieve the basic research objectives of the HTML as described in the following section.

Table 5.3. ORNL operating funds for FY 77 for basic and applied research on materials at elevated temperatures*

Group	Research Area	Basic Energy Sciences	NRC	NRA	Fusion Energy	LMFBR	Coal, Conservation, Other	Sub Total	Total
MECHANICAL BEHAVIOR	Fatigue			60(203)† 50(204)	50(22)	50(24) 175(28) 85(48)		470	3469
	Creep	44(37) 35(47)	200(124)	60(203) 100(204) 35(402)		50(24) 175(28) 400(50) 35(37) 235(48)		1369	
	Failure Mechanisms and Prediction		300(120) 135(119)	50(204) 70(402)	50(22)	50(24) 150(28) 100(50) 80(48)	50(21,Coal) 50(17,Coal)	1085	
	Mechanical Modeling		75(124)			200(50) 270(48)		545	
ENVIRONMENTAL INTERACTION	Erosion	44(37) 70(42)						114	1814
	Effects of Environment on Mechanical Properties			150(204) 25(402) 120(403)				295	
	H_2 Attack and Stress Corrosion Cracking	70(42) 100(65) 250(68)		50(204)				470	
	Corrosion, Oxidation Liquid Metal Inter.	200(45)	155(128)	40(204)	185(17)	60(28)	70(9,Coal) 225(Geothermal)	935	
PROPERTY MEASUREMENTS	Thermal Properties	250(45)	20(128)	35(203)			100(11,Conserv) 50(Nav.Graphite	455	1115
	Physical Properties	60(51)						60	
	Electrical and Optical Properties	100(45) 200(51)						300	
	Thermometry					300(16)		300	
STRUCTURAL CHARACTERIZATION	Surface Structure and Composition	70(45)		70(402)	75(21)			215	1028
	Microstructure and Microstruct. Stab.	33(37) 25(42) 210(47) 120(40)		20(403)	35(23)	55(37) 25(48)	50(Nav. Graphite)	573	
	Phase Equilibria and Kinetics	140(45)	100(128)					240	
MATERIALS SYNTHESIS AND PREPARATION	Composites and Mechanical Alloying	145(37)						145	776
	Non-Metal Processing	40(38)					50(Nav. Graphite)	90	
	Coatings and Coating Processes	33(37)					35(18,Coal)	68	
	Crystal Growth	73(37) 400(51)						473	
MATERIALS DEVELOPMENT	Alloy Development		35(33)	400(401) 20(403)		100(38)		555	906
	Ceramic Development	70(37)	81(33)				200(8, Conserv)	351	
	TOTAL	2782	1101	1355	395	2595	880		9108

*Excluding nuclear fuels and radiation effects work, and high temperature chemistry.

†Funding in $000 (number of pertinent 189).

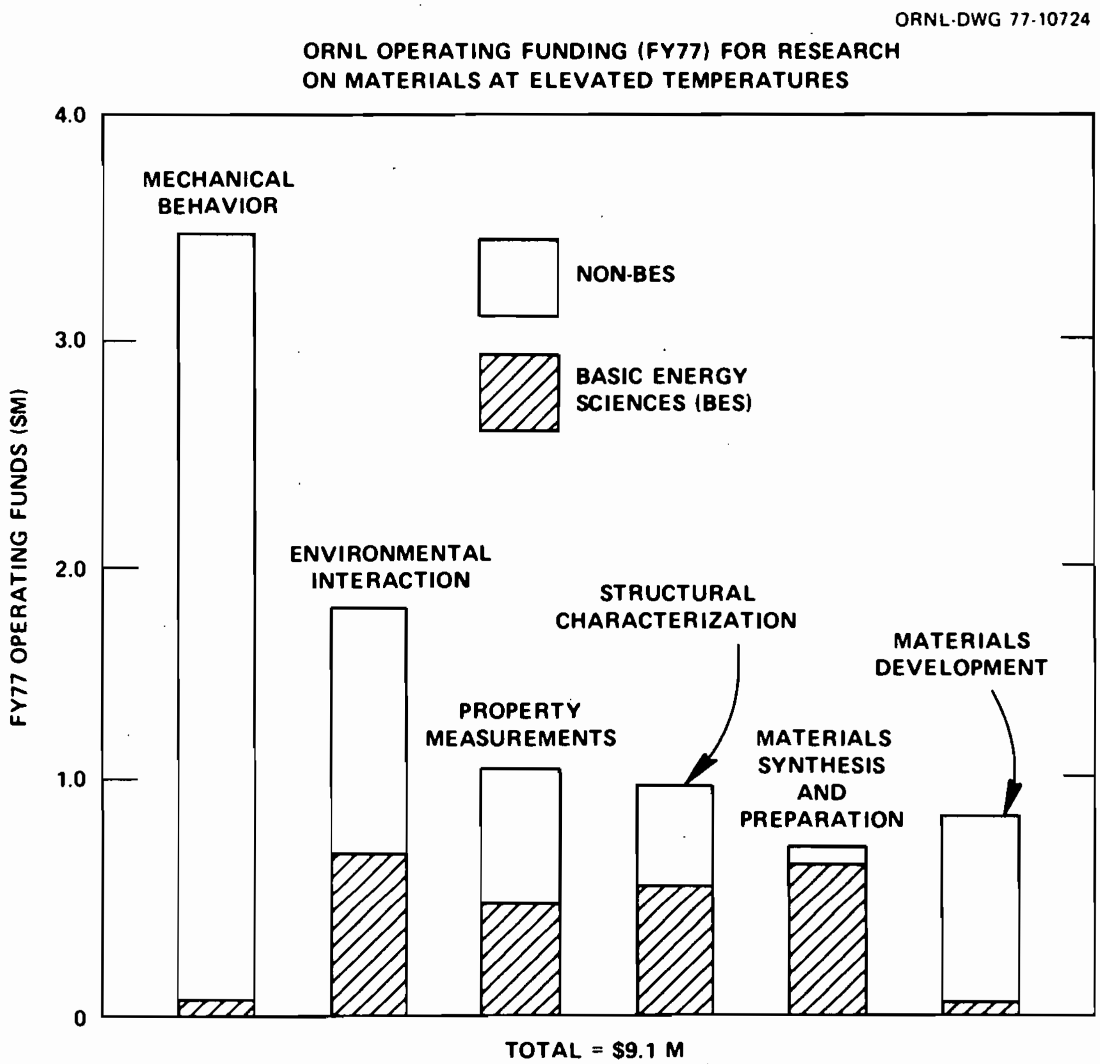

Fig. 5.2. Current research and development funding (FY 77) for materials at elevated temperatures for the groupings proposed for HTML.

6. RESEARCH PROGRAMS FOR HTML

A strong justification for HTML is based on technological needs of ERDA/DOE and the United States. This section describes the required basic research underlying these needs and categorizes these into research groupings for HTML. These categories reflect the interests of ERDA/DOE and, to a lesser degree, ORNL's program interests and proven capabilities. Also in this section we describe the research project areas envisioned for the professional staff of HTML.

6.1 POSSIBLE RESEARCH AREAS BASED ON TECHNOLOGICAL NEEDS

The review of technological problem areas requiring research support is found in Table 3.1. This information is condensed and presented in Table 6.1, in which selected research areas for materials at elevated temperatures are listed along with the energy systems affected by each research area. Work in these areas would affect nearly all the technological needs shown in Table 3.1. Thus, these areas form the basis for the research groupings for HTML described below.

6.2 RESEARCH GROUPINGS FOR HTML

The breadth of the research topics listed in Table 6.1 is far too large to allow research in all areas to be included in HTML. The research we propose to emphasize in the laboratory, *as it would exist at ORNL,* is given below in six research groupings. Each grouping is expected to employ about 12 professionals.

1. <u>Mechanical Behavior</u>
   Fatigue
   Creep
   Failure mechanisms and prediction
   Mechanical modeling

Table 6.1. Research areas for materials and materials processing at elevated temperatures

	Coal Liquefaction	Coal Gasification	Dir. Utilization of Coal	Adv. Dir. Util. of Coal (includes adv. gas-fired turbines)	Light Water Reactors	HTGR (GCFR)	LMFBR	MFE	Laser Fusion	Solar Energy	Geothermal Energy	Fuel Cells, Batteries and Thermionic Systems	Brayton Cycle and Stirling Engine	Conservation
MECHANICAL BEHAVIOR														
fatigue		X	X	X		X	X	XX*	X					
creep		X	X	XX		X		X					XX	
crack initiation and growth		X	X	X		X							X	
long term failure mech. and extrapolation	X	X	X	XX	X	X	XX	X	X		X			
mechanical modeling -- equation of state		X		X	X	X	X	X	X					
ENVIRONMENTAL INTERACTIONS														
erosion	XX	X	X	X									X	
effect of environment on mechanical properties		X	X	X		X							X	X
hydrogen attack	XX	X												
stress corrosion cracking	X	X	X	X	X	(X)	X	(X)	(X)		X			X
corrosion, oxidation mechanisms		X	XX	XX		X		X	X		X	X		XX
radiation effects					X	X	X	XX	X					
PHYSICAL CHARACTERIZATION														
thermal and physical properties		X		X	X	X	X			X			X	X
electrical and optical properties								X	X	X		X		
STRUCTURAL CHARACTERIZATION														
surface analysis	X							X	X					
structural stability		X	X	X		X	X	X	X			X	X	X
phase equilibria		X		X		X	X	X	X			X	X	X
weld characterization		X		X		X	X	X	X					
MATERIALS SYNTHESIS AND PREPARATION														
composites, mechanical alloying				X	X								X	
non-metal processing	X	X		X		X	X			XX		X	XX	X
coating techniques	X	X		X		X		X		XX		X		X
crystal growth										XX				
HIGH TEMPERATURE CHEMISTRY														
molten salt chemistry		X							X	X		X		
catalysis	X	XX										X		
electrochemistry												XX		

*Double X denotes area of research which is critical to the success of the energy system; a single X denotes an area which would have an important effect on the energy system.

2. Environmental Interactions

    Oxidation

    Erosion

    Hydrogen attack, stress corrosion cracking

    Corrosion, liquid metal interactions

    Effects of environment on mechanical properties

3. Physical Property Measurements

    Thermal properties

    Electrical, optical and magnetic properties

    Atomic transport

    Elastic properties

    Thermometry

4. Structural Characterization

    Surface structure and composition

    X-ray, neutron and electron diffraction

    Optical and electron microscopy

    Kinetics of structural transformations

5. Materials Synthesis and Preparation

    Composites, mechanical alloying

    Powder techniques

    Ceramic processing

    Vapor deposition methods, coatings

    Crystal growth

6. Materials Development

    Optimization of properties

    Material design

    Phase equilibria

One modification to the research areas of Table 6.1 has been made which we feel will improve the overall capabilities of HTML. This is the addition of a research group having the function of optimizing or developing materials. Because an essential aspect of an institute dedicated to fundamental work is the dissemination and application of its discoveries, this research group has been included in HTML to aid this process. It is proposed that a prominent part of the work in HTML be dedicated to the improvement of complex materials for complex uses at elevated temperatures, based on the fundamental results of the other HTML research groups. Work of this sort would be carried out in the Materials Development group.

6.3 RESEARCH PROGRAMS

Typical research that would be performed in each of these groups is discussed in the remainder of this section. In preparing this part of the proposal, certain factors limited the explicitness of the program descriptions; the class of problems that might be of interest to HTML will undoubtedly change over the period of years preceeding the construction of the HTML building. Furthermore, we may also expect some changes in the energy policies of the United States and of ORNL. Nevertheless, the research headings chosen as the basis for HTML are likely to apply, at least in general, for some time.

6.3.1 Mechanical Behavior

The subtopics under this major heading include inelastic deformation (plasticity and creep), fatigue, failure mechanisms and prediction, and modeling of mechanical processes. The personnel working in this area would have backgrounds encompassing solid mechanics, materials science, and the physics of crystal defects. The unifying research goal would be the understanding and prediction of mechanical behavior at temperatures $\geqslant 0.4\ T_m$ (T_m is the absolute melting point) based on the interaction of crystal defects and microstructural features.

On a macroscopic scale the above subtopics would be studied through uniaxial and multiaxial stress experiments to examine deformation, onset of failure, and the failure process. Included would be the identification and study of representation variables for derivations of phenomenological descriptions of material response which account for prior deformation and other histories experienced by the material. Some long-term (∿100,000-hr) experiments would be part of a larger effort to improve failure predictability, based on short-term experiments. On the microscopic scale those aspects of structure that affect behavior, such as the onset of tertiary creep, crack propagation rates, strain hardening, or recovery rates, will be studied phenomenologically and through theoretical treatments and modeling. Anelasticity, which may play an important role in the mechanical equation of state conceptualization, will be studied with respect to the microscopic mechanisms. Efforts will be made to evaluate modern concepts such as fracture or deformation maps and the mechanical equation of state. These evaluations will be correlated with analyses of microscopic behavior.

For materials such as ceramics having low or no ductility emphasis will be placed on the relationships between microstructural features and crack propagation. Reasons for the transition to significant plastic behavior in some ceramics at elevated temperature will be investigated.

The mechanical behavior group would also be involved in the mechanical characterization of new classes of materials synthesized at HTML, such as metal-metal oxide composites or mechanically alloyed materials.

6.3.2 Environmental Interaction

Erosion, corrosion (oxidation, sulfidation, etc.), and hydrogen attack are encountered in many high temperature, energy-related systems. These three phenomena are interrelated in the sense that erosion processes can destroy the protective qualities of a corrosion scale, while interactions between the scale and the erosive particle stream can accelerate erosion through the production of molten slags on the metal surfaces. Hydrogen attack on many metals probably can be limited only by the formation and maintenance of a compact oxide scale on the metal. Thus, both erosion and corrosion are likely to play an important role in determining the extent of hydrogen attack. However, all three processes are inherently so complex that a solution technique involving all three acting simultaneously offers little hope for success at this time. For this reason it is proposed that a "separate effects" program of research in erosion, corrosion, and hydrogen attack be initiated. Once a better understanding of the fundamental mechanisms in each process is attained, an attempt will be made to combine information from the three areas in order to suggest ways of minimizing the three forms of attack.

Very little is known concerning the fundamentals of erosion processes, and the initial research in this area will be to establish the parameters important in erosion phenomena. Erosion of both metals and ceramics will be considered, and electron microscopy will be used extensively in characterizing erosion effects.

The problem of corrosion will be approached from the point of view of characterizing the defect structures of the scales (both oxides and sulfides). Little information is available on this subject, especially for the sulfides. It is hoped that such research will provide guidelines for altering the defect concentration in such a way as to minimize corrosion of alloys. Corrosion of refractory ceramics will be studied also.

Recent results show that the diffusion of hydrogen in oxides is a much more complicated process that had been suspected previously. Because this process limits the rate of both ingress to and egress from the metallic components of a system, the diffusion of hydrogen in oxides and sulfides will be studied. The goal of this phase of the program will be to describe the diffusion process in atomistic terms. The characteristics of stress corrosion cracking at the higher temperatures ($\sim$500°C) may be related to the hydrogen transport through the surface layer.

One other area that will receive attention is the effect which environment has on deformation and fracture at elevated temperatures. It has been shown recently that impurities in gaseous environments can drastically change the microstructure and mechanical behavior of many materials through carbon or oxygen transfer. This degradation may be very specific to certain impurity concentrations. This area would be studied most conveniently using well-controlled atmosphere loops.

6.3.3 Physical Property Measurements

The initial efforts of this group will be to develop state-of-the-art equipment capable of extending the temperature range in which reliable information can be obtained. This would include the measurement of thermal, physical, electrical, magnetic, and optical properties in hostile environments and at temperatures up to and exceeding 3000°C. At these temperatures it is essential that highest precision thermometry be perfected, because this measurement would be basic to all the high temperature measurements. Techniques would include thermoelectric, resistance, optical, noise power, ultrasonic, and dynamic gas thermometry. Diffusion studies also will be an important part of the group's efforts. These will range from the study of the creation of migrating defects and their interaction with other crystalline defects to the generation of high temperature diffusion data for systems of interest.

The major emphasis will be placed on the properties of nonmetals because in the temperature range of interest to this group, few uses for metals exist. One topic of study will be the mechanisms for electric breakdown. The thermal properties of insulators also will be studied.

This group will be called upon regularly to measure the properties of materials created in the synthesis and preparation group in HTML; close coordination is expected between these groups. For example, a series of experiments involving the synthesis of interstitial compounds would be coupled with optical and electronic property measurements of these new materials.

6.3.4 Structural Characterization

The work of this group would be most central to the interests of HTML because much of our understanding of materials behavior is normally based on the structure. Emphasis will be placed on modifying or extending existing techniques to allow the monitoring of in situ phases and structures. To this end, high temperature equipment will be developed in x-ray diffraction, electron microscopy, optical microscopy, and surface characterization techniques (LEED, ESCA, SIMS, etc). It is expected that the 1-MeV electron microscope at ORNL, to be fitted with a high temperature environmental chamber, would be a key element for in situ studies of mechanical and environmental effects and phase stability. The Structural Characterization group would conduct basic research in the area of phase transformations and phase stability at elevated temperatures in both metallic and ceramic systems. High-resolution chemical analysis utilizing recent advances in electron microscopy would be performed. Other unique facilities at ORNL such as those for small angle x-ray diffraction and neutron scattering would be used.

Examples of research topics to be considered in this group are as follows: Optical studies of surfaces exposed to environmental attack would be essential to the understanding of corrosion or oxidation mechanisms. Theoretical work on the band structure of very stable high temperature compounds would be performed. The properties of intrinsic defects at high temperatures will be examined theoretically, also, to provide a basis for understanding the kinetics of defect-controlled structural changes. The structural nature of solid solutions will be examined using x-ray diffuse scattering to determine localized atomic displacements.

6.3.5 Materials Synthesis and Preparation

The Materials Synthesis and Preparation group's primary responsibility would be to supply research materials to the other HTML groups. It would also extend the present capabilities for synthesis of new high temperature alloys, compounds, ceramics, and composite materials. In this regard basic research on eutectic solidification, sintering mechanisms, and chemical vapor deposition, for example, would be conducted. The growth of single crystals would be an important part of the total effort, and crystals of new materials will require novel preparation techniques. Hot mechanical fabrication processes will be included as part of the preparation methods. Pressure synthesis of new materials and physical vapor deposition in reactive environments will be used to produce new materials with unique properties. A substantial effort will be maintained in the development and research on coatings for protection of components from environmental degradation at elevated temperatures.

Obviously this group's efforts will be closely coupled with the characterization studies in order for the other groups to be able to conduct meaningful experiments.

6.3.6 Materials Development

The group would perform some basic research in selected areas, but would function primarily to extend to complex materials the understanding gained in the other groups' investigations of idealized materials. It would serve to strengthen the link between the basic work of HTML and the applied interests of ORNL and ERDA/DOE. In addition, work would be done on materials requiring an optimization of several qualities simultaneously, such as good high temperature strength, corrosion resistance, and thermal conductivity. Frequently the optimization of one property may seriously degrade another; thus, familiarity with many aspects of behavior will be required by personnel in the Materials Development group.

One topic to receive attention is the achievement of essential properties in materials in a manner that does not require significant amounts of strategic materials or materials that are not energy-intensive to produce.

Some of the group's fundamental research would be in the area of phase equilibria and thermodynamics of multicomponent systems. Computer calculations of phase equilibria will be carried out to assist in the development of particular structures.

7. EQUIPMENT, PERSONNEL, AND OPERATING REQUIREMENTS OF HTML

7.1 MAJOR EQUIPMENT

The specialized equipment for HTML will constitute an important resource for ERDA/DOE. Much of this equipment is listed below, along with current (FY 77) prices. This list reflects many of the activities described in the Research Programs for HTML in Sect. 6. As was pointed out earlier, based on possible changes in interests and policies, this list should be considered tentative. The research programs have not been sufficiently well defined to permit other than an illustrative list to be provided at this time. (Also, because this equipment is listed in FY 77 dollars, the fraction of the equipment actually purchased will depend on how soon the purchases are made.) In many cases it probably will be necessary to develop new types of equipment needed for these high temperature studies.

Along with the new equipment *a significant amount of relevant equipment which already exists at ORNL will be moved into HTML.* Without a more complete description of the research programs and personnel involved, it is difficult to provide a list of this equipment. However, an estimate of the value of this equipment was made by itemizing in detail the cost of the apparata associated with one typical, existing group at ORNL. This group, the Ceramic Studies Group of the Metals and Ceramics Division, contains research and personnel which is rather well suited for transfer to HTML, and its equipment requirements were taken as a basis for calculating the overall equipment value. Including the replacement value of the Hitachi 1-MeV microscope, which is expected to be moved to HTML, we assume an overall total figure of ∿\$3.5 million worth of major, existing equipment to be moved to HTML. This will include items such as RF power units, ceramic processing equipment, certain apparatus for measuring physical properties, crystal growers, furnaces, etc.

1. Mechanical Behavior

Programmable tension/fatigue/stress relaxation machines:

High load (2), medium load (4), low load (10)	$ 600*
High T, high vacuum creep testers (30)	400
Creep test machines (30)	300
Multiaxial creep/fatigue machines (2)	100
High strain rate, high T apparatus	100
High load, high T creep testers (3)	75
	$1,575

2. Environmental Interaction

Environmental loops (2) for studying corrosion and surface reactions, fatigue, and failure mechanisms in an elevated temperature/controlled atmosphere system:

Engineering design	$ 140
Control equipment (T, P, flow, etc.)	100
On-line analysis equipment (mass spectrometer, gas chromatograph, voltammeter)	100
Construction	160
Loop components	200
	$ 700

3. Property Measurements

Thermal conductivity systems (6)	$ 115
Thermal diffusivity apparatus (2)	50
Resistivity and thermopower apparatus	60
Elastic constant equipment	60
Thermal expansion apparatus (2)	40
Calorimeters (2)	40
Magnetic susceptibility unit	30
Fourier transform spectrometer	150
Nitrogen pumped dye laser and support equipment	50
Absorption/reflectance spectrometer for UV-VIS-IR	50
Modulation ellipsometer	18
Support equipment (potentiometers, controllers, cells, etc.)	130
	$ 793

*Numbers in $000.

4. Structural Characterization

200-kV transmission electron microscope with dispersive x-ray detector	$ 300
Scanning electron microscope	90
High T, high resolution mass spectrometer	95
Auger electron spectrometer	90
X-ray facility	80
Improvements and modifications to the 1-MeV electron microscope	65
Laser Raman apparatus	65
ESCA unit	50
Low energy electron diffraction unit	40
Secondary ion mass spectrometry unit	30
Support equipment (spark cutter, microscopes, gas analyzers, etc.)	85
	$ 990

5. Materials Synthesis and Preparation Materials Development

Electronbeam furnace	$ 150
100-kW induction furnace	120
Thermogravimetric analyzer	85
High T differential thermal analyzer	80
Czochralski crystal growers (2)	100
Pressurized crystal grower	80
Arc melters (2)	70
Alloying arc-furnace	50
RF power supplies (50 kW, 30 kW)	45
Zone refiner	40
Hot press, hot hardness tester	52
High T, high vacuum furnace	35
Pt-Rh wound furnaces (1700°C) (4)	32
Instron testing machine	30
PVD, CVD systems	35
Support equipment (furnaces, controllers, balances, vacuum equipment, etc.)	200
	$1,204

6. Other

Machine shop equipment	$ 147
Terminals, teletype, keypunch display equipment, and copier	35
Hewlett Packard desk calculator and plotter (2)	30
	$ 212

SUBTOTAL	$5,474
7. Computer hardware (10% of subtotal)	$ 547
TOTAL	$6,021

7.2 PERSONNEL

The nucleus of the professional staff would be formed from people already working at ORNL in the Metals and Ceramics Division, Solid State Division, Chemistry Division, Engineering Technology Division, Instrumentation and Controls Divisions, and perhaps other divisions. Of the total professional staff of 70 scientists we expect that less than one half will be taken from the present ORNL staff. It is expected that about 90% of this staff will be composed of experimental scientists, with the remaining 10% theoreticians. Thirty-two technicians will assist in the experimental research; thus, HTML will have a ratio of experimental scientists to technicians of about 2 to 1.

The total staffing requirements are listed as follows:

Scientific research staff	70
Technicians	32
Director, plus administrative staff (including secretaries)	20
Instrument professionals	2
Computer programmer	1
Craft support (Plant and Equipment Division)	15
	140

7.3 OPERATION

HTML is designed for a staff of about 140, requiring a total operating funding of ∿$9 million per year (FY 77 dollars). The initial staffing will be at a level slightly over half the final complement of people. The funding at this time, assumed to be the beginning of FY 82, would be roughly 60% from the Basic Energy Sciences Division with 40% from applied funding sources (mainly from the ERDA/DOE program divisions). Much of this total initial funding would be redirected funds that presently support projects that are related to or are similar to work to be pursued in HTML. The remainder of the funding for initial operation would be new BES support. Furthermore, the growth from the initial staffing of HTML to its full size is envisioned to be accomplished primarily through increased BES funding. When the staff is complete, it is expected that two-thirds of the support will come from BES, with one-third from applied research funding sources.

The relation of HTML to the ERDA/DOE programs is shown in Fig. 7.1. This diagram indicates the following points relative to HTML's operation:

1. HTML would house research that extends from basic scientific studies to ones having immediate effect on the ERDA/DOE mission.

2. The basic research groups of HTML (Mechanical Behavior, Environmental Interactions, Structural Characterization, and Property Measurements) would have an important interaction with the Materials Synthesis and Preparation and the Materials Development groups.

3. Each of the groups would serve particular functions in relation to the ERDA/DOE materials science and applied programs.

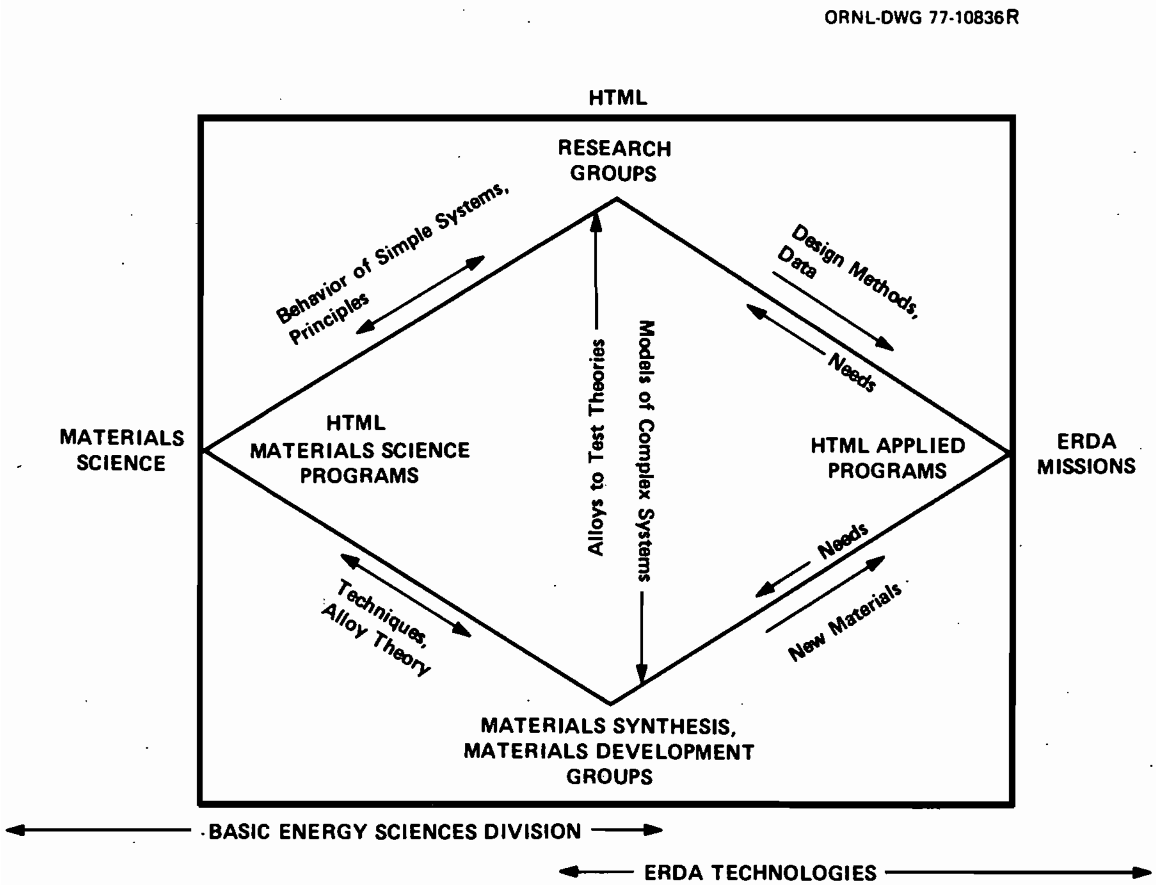

Fig. 7.1. The relationship between HTML and the Materials Science and Applied Programs of ERDA/DOE, as well as some of the internal structure of HTML.

8. THE HTML BUILDING

The proposed project, as presently conceived and as based on the current estimate of the programmatic needs, will consist of a new building that will provide space for research laboratories, offices, and service areas and, based on conceptual design considerations, will contain a total area of approximately 80,000 square feet.

Site selection criteria dictated that the facility be located on a site outside the main laboratory perimeter fence permitting ready access by visiting scientists. This area contains the Electron Linear Accelerator, the Oak Ridge Isochronous Cyclotron, and the Heavy Ion Facility, which are nationally prominent facilities that attract many visiting physicists who conduct experiments on a time-sharing basis. Specifically, the site selected is located southwest of the existing high energy complex and south of White Oak Avenue and White Oak Creek (Fig. 8.1). Utilities will be extended from existing distribution systems. Planned long-term experiments will be protected against power failure by emergency power from diesel motor generator sets. Drainage from the facility will flow to existing plant collection and treatment systems. Improvements to land will include paved service roads, parking areas, walks, and landscaping.

The first conceptual study of HTML, which was made by the engineering staff at ORNL, utilized an L-shaped building to accommodate the moderately sloping site. The preliminary plan of this building called for about 28,000 square feet of laboratory space in a building having a partial basement with two floors above. Provision is made for specialized equipment needs (e.g., the 1-MeV microscope and certain machinery requiring high bay area) and for offices for the 140 persons in the building. Services such as a machine shop, canteen, change rooms, key punch room, conference rooms, etc. are included.

A conceptual design study is currently being conducted by Rust Engineering, an architect/engineering firm from Birmingham, Alabama. Detailed drawings

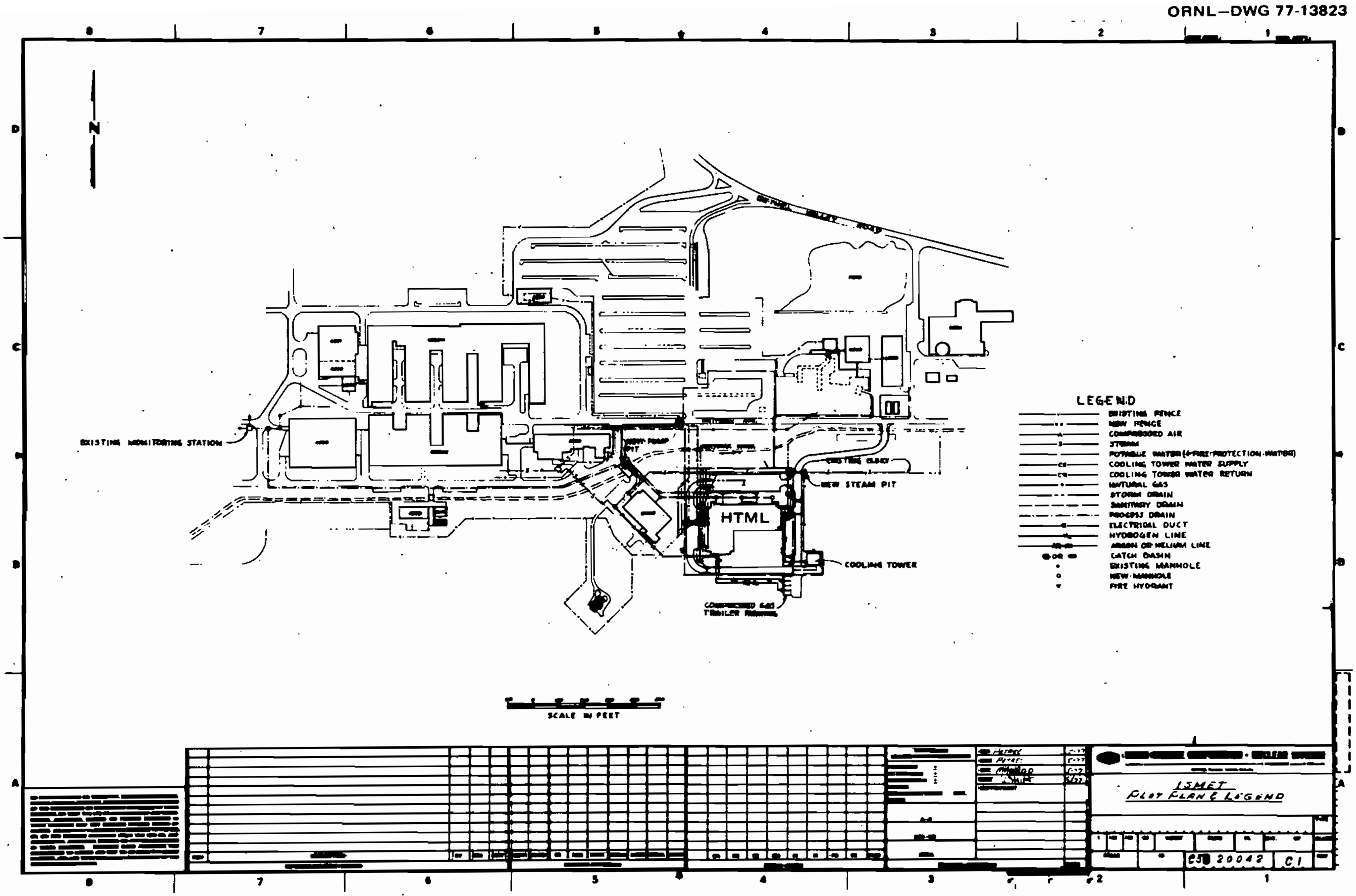

Fig. 8.1. The location of HTML at Oak Ridge National Laboratory.

conforming to the prescribed laboratory requirements should be available in October 1977. Included here (Fig. 8.2) is the preliminary rendering from this conceptual design.

The project schedule is outlined in Fig. 8.3, based on the passage of HTML as an appropriation for FY 1979.

ORNL DWG 77-14602

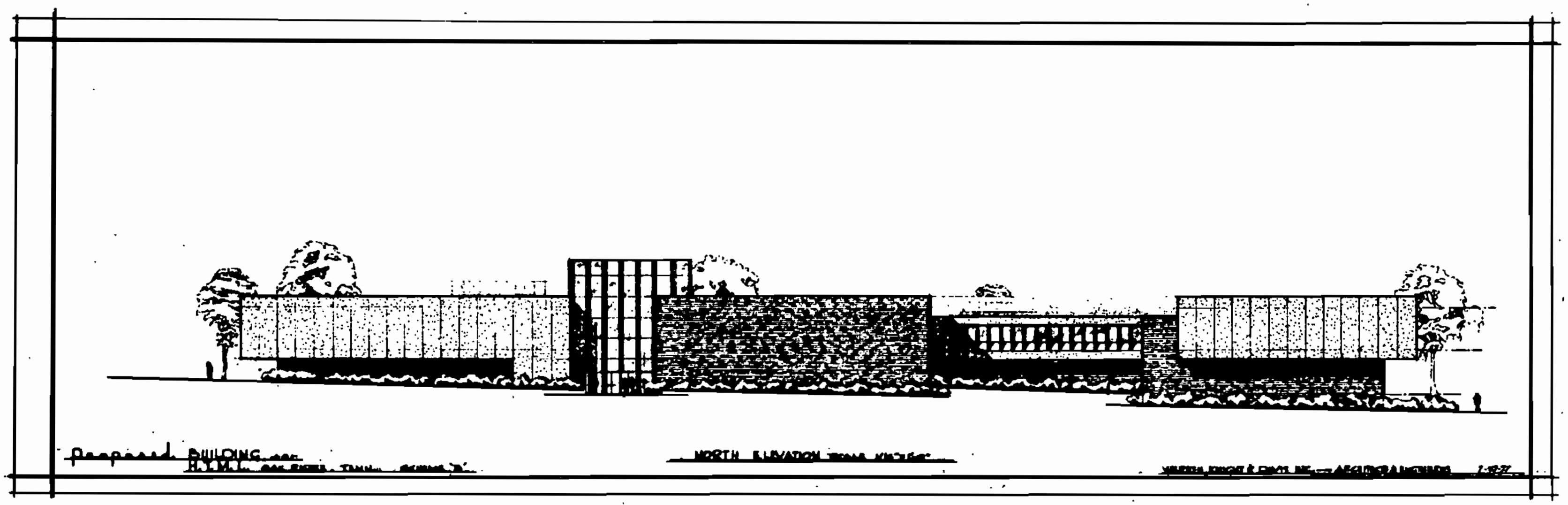

Fig. 8.2. Proposed building for High Temperature Materials Laboratory.

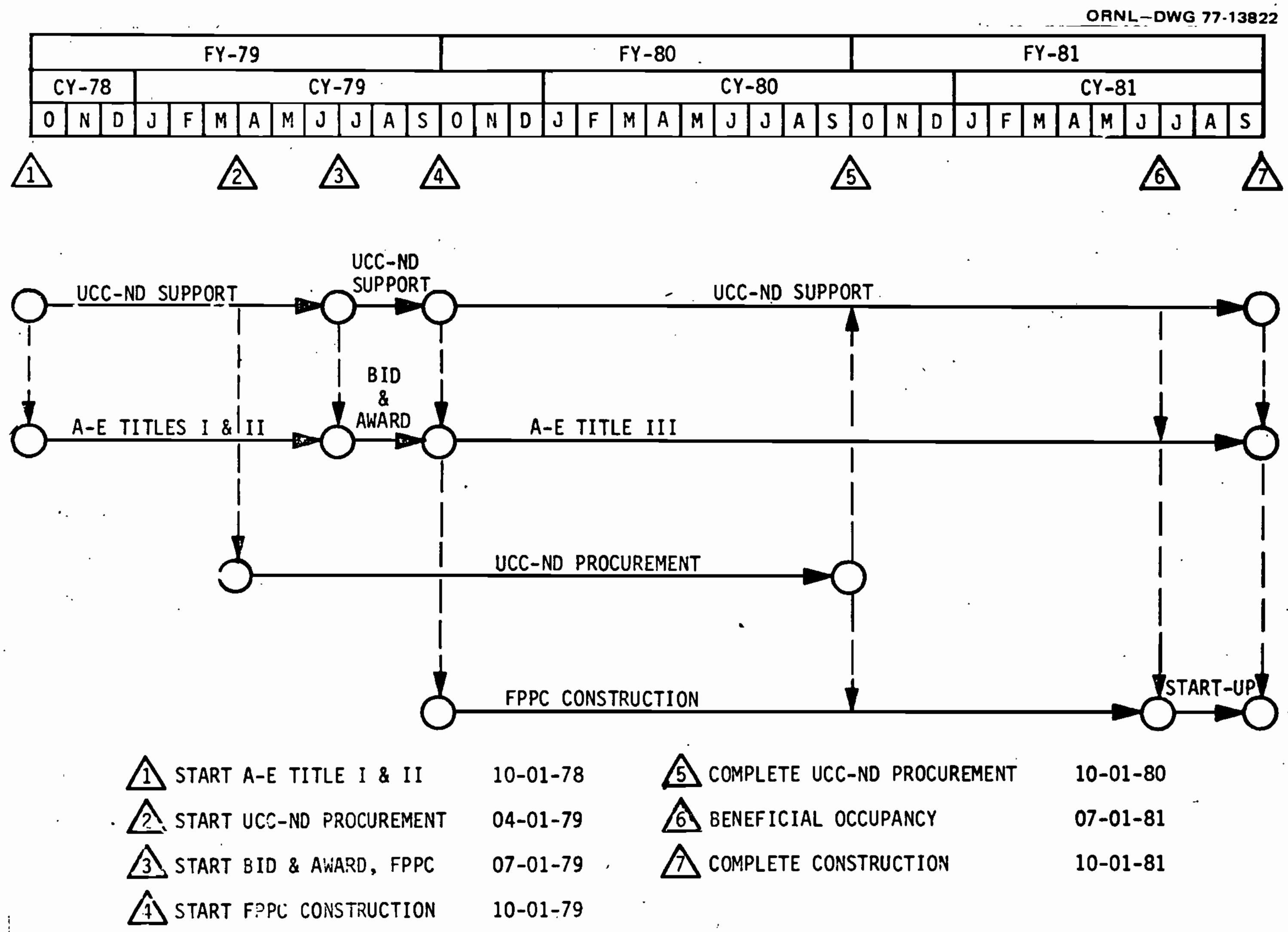

Fig. 8.3. Project schedule for HTML.

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