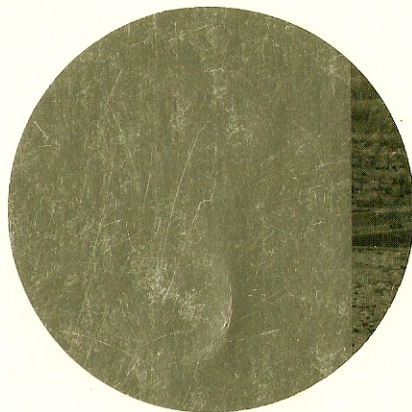


NUCLEAR POWER....

Progress is paced by materials technology

GENERAL  ELECTRIC



NUCLEAR POWER

Never before in the history of mankind has the phrase "Progress is Paced by Materials Technology" been more applicable than in this rapidly evolving technological age in which we live. Industrialization as we know it began with the advent of the steam engine; after a hundred-odd years, the "steam age" was largely supplanted by the miracle of electric power, foundation of all our subsequent progress. Paralleling the development of the electrical era was the air age. Before the aviation industry celebrated its golden anniversary, we found ourselves in the nuclear and space ages. The nuclear industry matured in less than twenty years and the space industry in only ten.

Many factors have contributed to this fantastically quickening pace of technological progress,

but perhaps the key to it all has been the ready availability of new, ever-better materials and systems capable of meeting the continuously more demanding performance characteristics required by design engineers. Many significant advances contributing to this accelerating progress were spin-offs from previous programs. Much of the research conducted under these projects was so unique that it was continued, often with outstanding results, by the General Electric Company's Nuclear Materials and Propulsion Operation.

Although only a partial glimpse is possible in these few pages, this booklet is indicative of the overall diversity and capabilities of the Nuclear Materials and Propulsion Operation.

This publication is planned to describe to government, industrial, scientific, community, and education leaders the progress being made in the field of nuclear energy at the Nuclear Materials and Propulsion Operation (NMPO). General Electric operates NMPO for the United States Atomic Energy Commission. It is a component of the Nuclear Technology Department which is a part of the Company's Nuclear Energy Division.

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Materials' phase boundaries are determined in this inductively heated furnace. The melting point of urania, for example, was found to range from about 4450°F to nearly 5200°F as the oxygen-to-uranium ratio is increased from $UO_{1.65}$ to UO_2 .

NUCLEAR POWER...

Progress is paced by materials technology

Meeting many of the critical technological challenges posed by the nuclear and aerospace ages, General Electric's Nuclear Materials and Propulsion Operation (NMPO) engages in a broad spectrum of research and development projects. Within a 12-acre site in the Evendale suburb of Cincinnati, Ohio, over 500,000 square feet of space are devoted to a unique complex of laboratories and shops, manned by highly qualified personnel, well over a hundred of whom are scientists and engineers. Detailed research is conducted in many areas, particularly in high-temperature materials technology and space reactor systems.

Adjunct staffs are stationed at the AEC's National Reactor Testing Station in Idaho and Oak Ridge National Laboratory for in-pile testing of materials and fuel elements. About half of the 50 employees at the Idaho location are scientists or engineers engaged in work on the "710" reactor, the thermionic space power reactor, a special rocket reactor, reactor safety programs, and materials irradiations. Prototype reactor testing and fast reactor criticals can be operated at this site.

The first of NMPO's two major goals is to develop new or improved heat- and radiation-resistant materials for use in nuclear, aerospace, and other



Metallic and non-metallic materials are densified by vacuum hot pressing, a process which eliminates atmospheric contamination and also removes volatile impurities. Densities up to 100 percent of theoretical are obtained.

applications. Equipment and facilities have been acquired and skills developed that enable NMPO personnel to explore material capabilities almost to their absolute limits. Implicit in most of this work are high temperatures, often approaching and even exceeding the materials' melting points.

The second objective is to develop nuclear power sources and energy-producing systems incorporating the information derived from the materials work. Spin-offs from the basic technological program are utilized in the 710 power reactor, in studies for special radioisotope power packages, and for applications of nuclear energy in the field of oceanics.

The "710" is a high-power-density, fast-spectrum, refractory-metal reactor being designed for use with various energy conversion cycles for electrical power generation in space missions. Well underway, the 710 program has concentrated on demonstrating a highly reliable fuel system compatible primarily with Brayton cycle coolants but also with the Rankine cycle and, possibly, stationary converters.

High-power-density, high-temperature-capability radioisotope fuel elements are being studied for use in the AEC-NASA radioisotope power packages. Allied to this effort, materials and process advancements are leading to high-reliability stationary conversion devices.

During the course of this demanding work, many new concepts and techniques have emerged. Oxide-dispersion fuel elements (nuclear fuel dispersed in a metallic matrix) were developed to meet stringent temperature and radiation conditions encountered in advanced reactor applications. Benefiting many reactor programs, solid moderator

materials were pioneered in the Evendale laboratories. Lightweight materials with excellent shielding properties were developed and are in wide use today as a result of shielding theory and design work, and new materials born in NMPO labs. Remote handling equipment, high-temperature controls and instrumentation, nuclear theory, safety measures, thermal insulation . . . these and many other technological areas have been explored or advanced.

Currently, many projects of national scope are being supported by the advanced materials research performed at NMPO. The refractory metals and their alloys are being studied for effects of radiation as well as high-temperature engineering properties in structural and fuel cladding applications. Advanced materials for nuclear fuel elements, moderators, controls, and shielding are under development for long-life, high-temperature applications. Ferritic alloys (iron-chromium-aluminum-yttrium) are being investigated as fuel claddings for the AEC's fast breeder reactor program. New processing methods for ThO_2 , UO_2 , and other fuel materials are being developed for various end users.

NMPO, then, is many industries, many extremes: high temperatures . . . cryogenics; advanced nuclear research . . . sheet metal fabrication; massive forgings . . . minute instrumentation; high pressures . . . near-perfect vacuums; prosaic materials . . . toxic, pyrophoric, or radioactive compounds.

In the following pages, a closer look is offered at only a few examples of the facilities, equipment, and personnel that, in combination and overall potential, can best be described by only one word . . . **UNIQUE.**

FACILITIES

An extensive variety of equipment and facilities has been acquired or specially designed and built for the NMPO laboratories. Some of these "tools" are unique; some are standard items. Still others are standard equipment being used in unexpected ways.

The examples shown here illustrate only part of this complexity.

HOT GAS ISOSTATIC PRESSING (AUTOCLAVE) EQUIPMENT

The first AEC laboratory to make extensive use of hot gas isostatic pressing (autoclaving), NMPO now has three high-temperature, high-pressure autoclaves in operation. These 15,000-psi units are used in the fabrication, consolidation, and solid-state diffusion bonding of materials. Two units are capable of temperatures as high as 3200°F while the third, equipped with a special beryllium oxide

Used to bond clad fuel elements, moderators, and metal-to-ceramic seals, this high-pressure autoclave operates under maximum conditions of 3200°F and 15,000 psi. True metallurgical bonds are obtained.



muffle, is useful to 4000°F; the electrical heating elements are stranded tungsten or molybdenum windings.

Hot gas isostatic pressing equipment is used for applications with such stringent requirements that no other known fabrication process has proved satisfactory. These applications include integral isotopic heat source containers without weldments; clad, fueled, hydrided yttrium for advanced SNAP-8 reactor applications; metal-to-ceramic seals widely used in the thermionic SNAP systems; and hollow titanium alloy buckets for SST engines. It is also used in consolidation and terminal bonding of lead telluride shapes for SNAP and terrestrial power source conversion power plants.

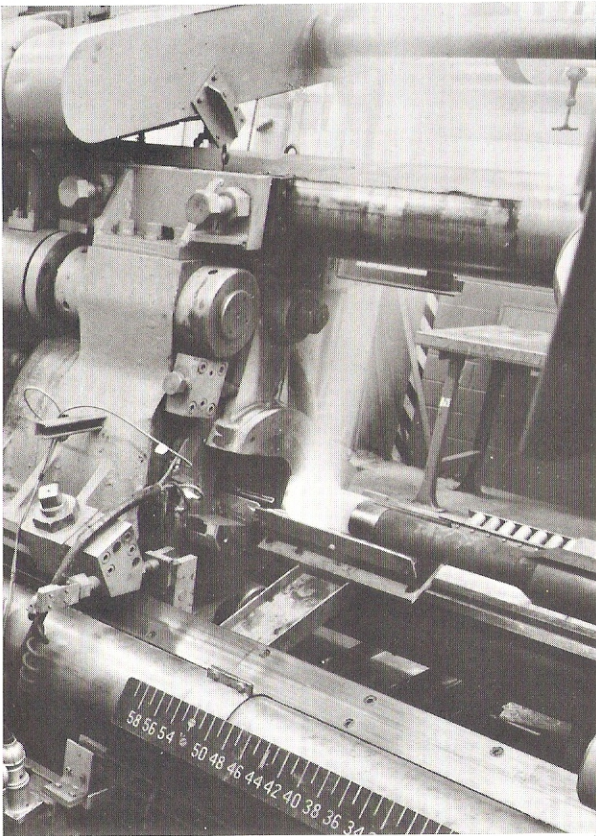
Niobium-to-aluminum oxide seals (before assembly, after isostatic pressing, and after machining) serve as hermetically sealed insulators in direct energy conversion devices.



EXTRUSION PRESS

Another specialized facility is the 1250-ton extrusion press with an unusually high ram speed — 17 inches per second — for its capacity. Used to extrude the highest melting and toughest alloys known, it is equipped with an automated induction billet heater capable of rapidly heating large refractory alloy billets to temperatures up to 4000°F

Extruding a super-alloy billet.



in inert atmospheres. The work piece is automatically discharged from the heater, transferred to the press, and extruded in reductions of up to 20:1, all in less than 15 seconds. The high ram speed permits the use of hardened steel dies whose melting point is only 2650°F, far below the temperature of the billet.

This press supports the fabrication of special alloys required for the Poodle program, SNAP thermionics, 710 reactor program, Hanford control rods, chromium alloys for the SST, Livermore SNAP-50 programs, and isotopic heat source containment.

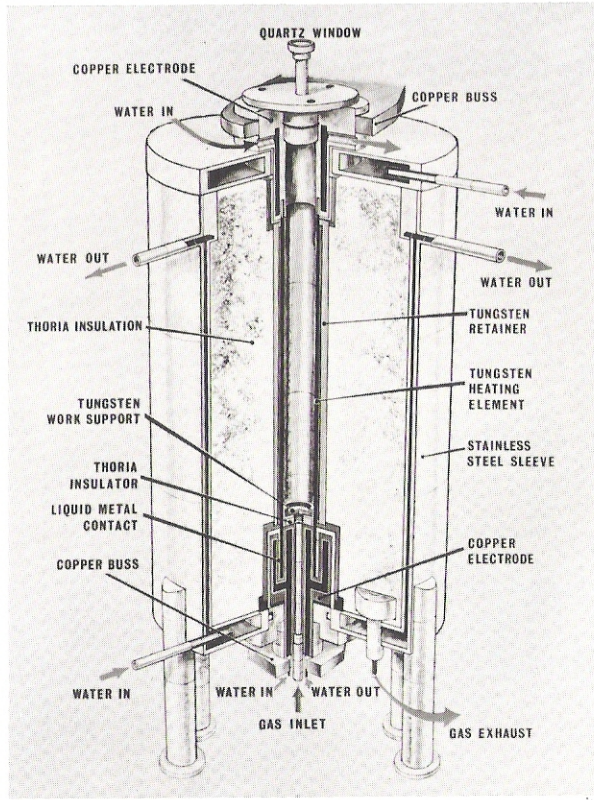
Cross section of a co-extruded reactor control rod; cladding — Inconel 600, core — dysprosium oxide dispersed in nickel.



HIGH-TEMPERATURE FURNACES

NMPO has more high-temperature furnaces operating at 5000°F and above, in inert or reducing atmospheres, than any other facility in the United States. Required to operate at these temperatures continuously for hundreds and even thousands of hours, these furnaces are also subjected to rapid thermal cycling. Many other electrical furnaces are used for experimental work in intermediate temperature ranges from 2000° to 3500°F.

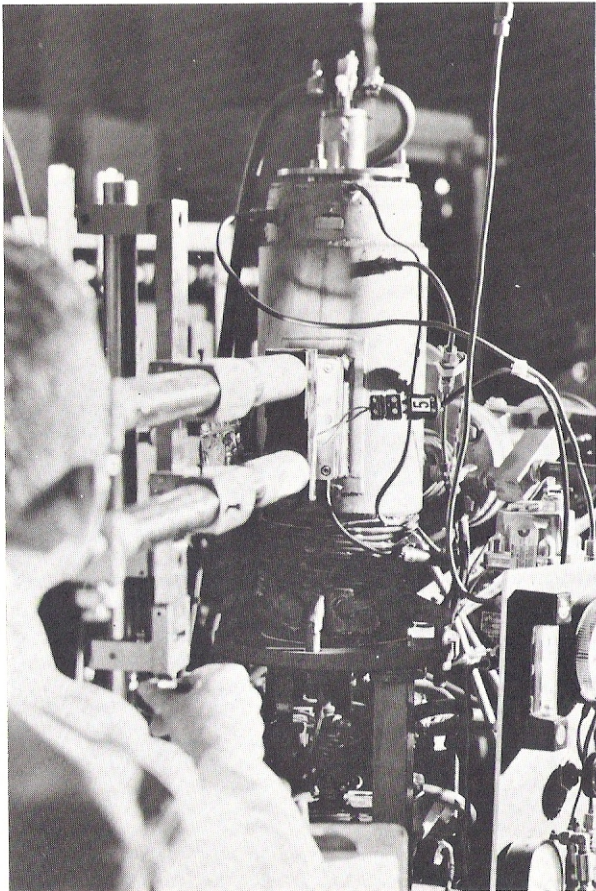
Cutaway of a typical NMPO high-temperature furnace.



New tungsten-base alloys, sintered and homogenized in these furnaces, remain ductile at room temperature regardless of prior elevated-temperature exposure. Also, unlike the molybdenum currently available commercially, shapes of this alloy can be produced that are not glass-brittle after welding or heating to high temperatures.

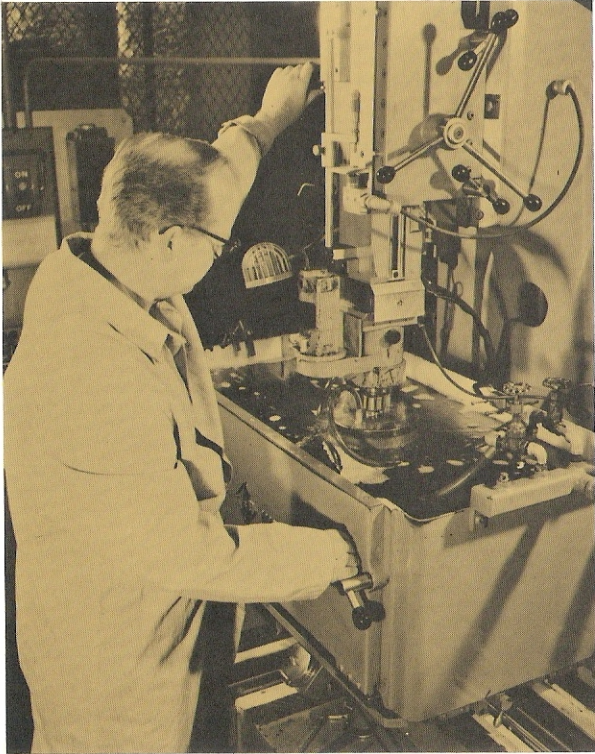
Fifteen of the 5000°F furnaces were designed and built for other government laboratories and contractors.

Using an optical extensometer, technician measures strain on a test specimen in a creep-rupture furnace.



DEVELOPMENT MANUFACTURING

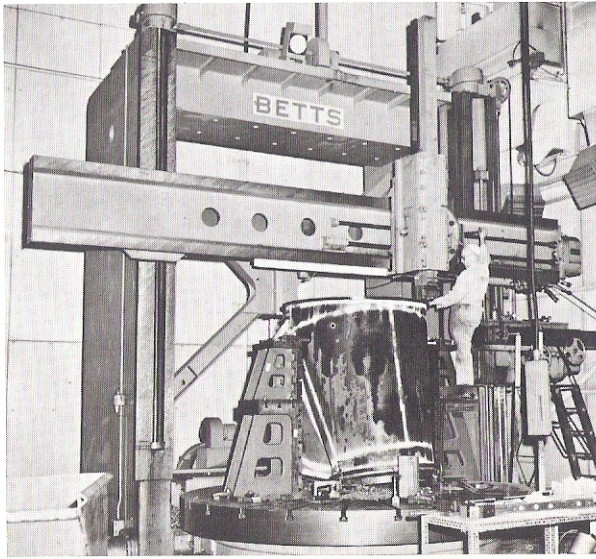
Although portions of Development Manufacturing resemble an ordinary machine shop, such similarity is only superficial. Twelve-foot vertical boring mills and handling capacities of up to 30 tons offer startling contrast to miniature, precision jewelers' lathes turning out parts almost too small to be seen with the naked eye. Sheet metal is rolled, pressed, sheared, and welded from foil thickness to plates over two inches thick. Difficult and exotic materials — the refractory metals, ceramics, Hastelloy X, beryllium, zirconium, enriched uranium, Inconel X, Rene' 41, among others — are processed routinely.



Fueled and unfueled in-reactor test specimens, together with their complex instrumentation, are prepared and hardware is manufactured for reactors, shielding, and critical experiments. Unique components for the C5A and SST engines and the Minuteman ICBM are also built in these shops. Manufacturing techniques and limitations often must be established before new materials developed for these programs can be worked. This is frequently the most difficult and challenging phase. Electrical discharge machining, electron-beam welding, diamond machining, and ultrasonic drilling are only a few of the methods available in NMPO Development Manufacturing.

A refractory metal being machined by electro-spark erosion in an EDM machine.

Betts Vertical Boring Mill machines components up to 144 inches in diameter and 150 inches high.



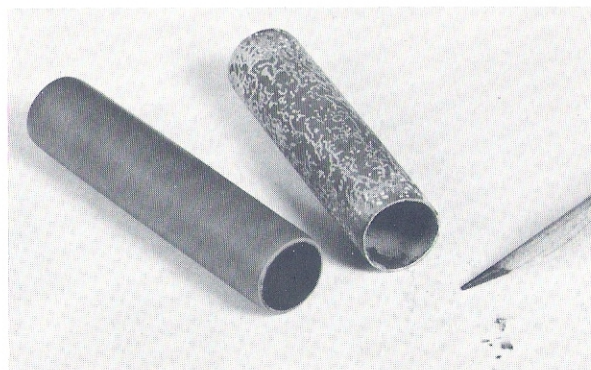
MATERIALS AND FABRICATION PROCESSES

Among the many challenges confronting NMPO scientists and engineers is the demand for new materials with much higher performance characteristics than ever previously required. Before such materials can be developed, often-unique equipment and techniques to produce them must first be devised.

OXIDATION-RESISTANT ALLOYS

As one of the nation's leading centers for the development of ductile oxidation-resistant materials, NMPO's laboratories have developed alloys based on nickel, chromium, ferritic and austenitic iron, and the noble metals for long-time service (1,000 to over 10,000 hours) at temperatures well above 2000°F. Fe-Cr-Al-Y alloys, the most oxidation-resistant metals yet found for service up to 2450°F, were identified. Due to their excellent nuclear properties and resistance to radiation-induced embrittlement, these alloys may be useful as fuel element cladding for fast breeder reactors. They are also being investigated, in a cooperative venture between the UKAEA and the USAEC (through NMPO), for advanced British helium-cooled,

Adding yttrium to iron-base alloys greatly improves oxidation resistance. Both specimens were heated in air for 20 hours at 2200°F.



Complex alloys containing reactive metals are produced in industrial quantities and sizes in this 500-pound vacuum induction melting facility. Starting with materials so pure that no reactive flux is necessary, and avoiding atmospheric reactions by melting in vacuum, this furnace can contain such materials as titanium, yttrium, tantalum, and uranium where other types cannot.



graphite-moderated central power reactors. 500-pound melts of these alloys are produced to a level of quality consistently surpassing that of commercially available alloys.

Chromium-base alloys are of interest for high-temperature oxidation resistance because of their high melting points. Combined with yttrium, ruthenium, or rhenium, such alloys possess excellent room-temperature ductility. This work supports NASA investigations of materials for turbine buckets in the SST project.

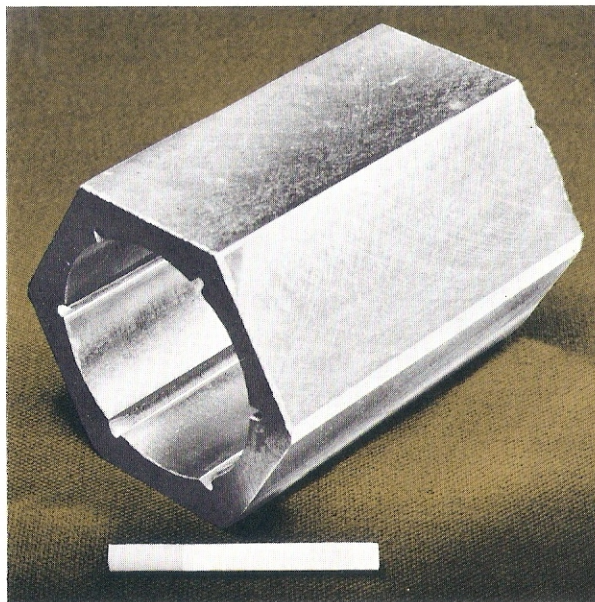
Air scoop turbine rotors of oxidation-resistant Inconel 718 are machined for application to a scaled-down version of the TF-39; 154 dimensions are generated. Each segment is worth more than its weight in gold.



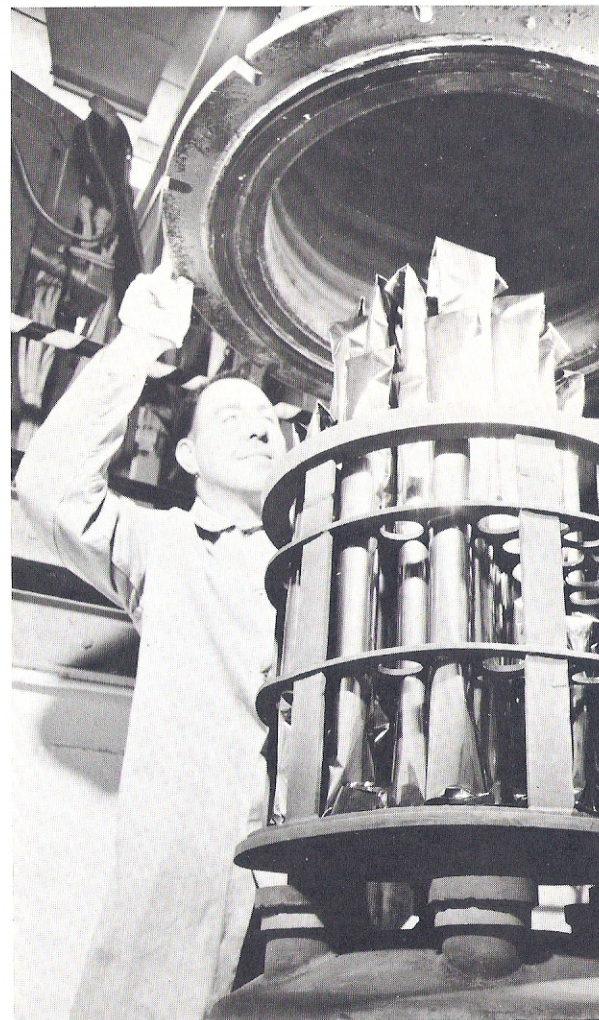
HYDRIDES; MODERATOR, CONTROL, AND SHIELD MATERIALS

Solid metallic hydrides and the unique techniques required to produce them were discovered by NMPO scientists in 1955-56. These unusual materials, containing up to twice as much hydrogen per unit volume as liquid hydrogen itself, now serve as nuclear shielding and moderators. Yttrium, zirconium, and titanium in massive shapes weighing a ton or more are hydrided at NMPO.

Machined, heavily hydrided zirconium hexagon for reactor moderator applications.



A technician prepares foil-wrapped zirconium rods for hydriding to N_H as high as 8.5.



Yttrium was merely a very scarce laboratory curiosity until Evendale scientists showed its unique values and then, in cooperation with Ames Laboratory, Michigan Chemical Corporation, and others, developed both sources and an industry for preparing it in tonnage quantities. Today, yttrium is employed in many non-nuclear applications, including use as a phosphor in color television tubes which substantially improves color fidelity. Fueled yttrium hydride is of value as a moderator material in advanced space system applications.

Fuel elements for TRIGA and SNAP-8 reactors consist of nuclear fuel incorporated in zirconium hydride. Unfueled hydrided zirconium is being considered for the German KNB reactor's moderator. Lightweight titanium hydride shielding, with an extraordinarily high hydrogen content, supports the LOFT, SNAP-8, and NERVA projects.

A dysprosium oxide cermet control rod clad in a heat-resistant alloy for 1800°F service in a helium-cooled, graphite production reactor is being developed for the AEC. Other control rods developed by NMPO scientists are stable in service at temperatures as high as 3000°F.

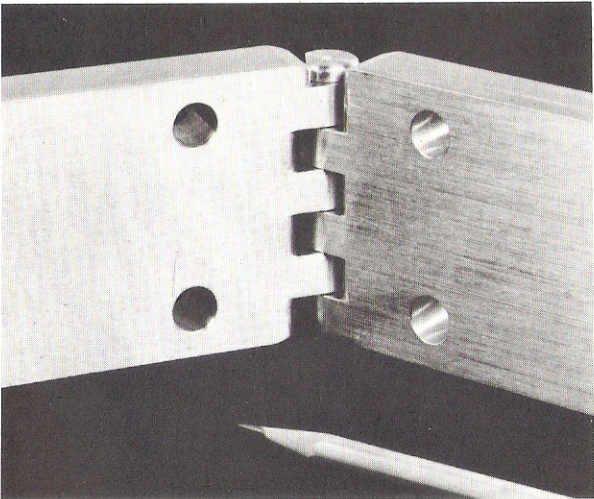
BERYLLIUM FABRICATION

To provide safe working conditions for the handling of radioactive and toxic materials such as U^{235} and beryllium, NMPO laboratories and production bays are equipped with special environmental purification and control systems. Much of the early work on beryllium carbide was conducted here, and procedures were established for producing microcrystalline beryllium oxide powders

of very high purity and excellent sintering properties. NMPO also fabricated the initial fuel elements for the TORY II reactor test.

Beryllium metal has been worked in a variety of shapes, from massive reactor reflectors to thin configurations for space radiators. Lightweight beryllium buckets for advanced gas turbine engines are also being developed by Evendale metallurgists.

Prototype hinge assembly of a co-extruded, articulated, Inconel 600 control rod flame-sprayed with chromium carbide.



Mixing beryllium oxide powder under closely controlled conditions.



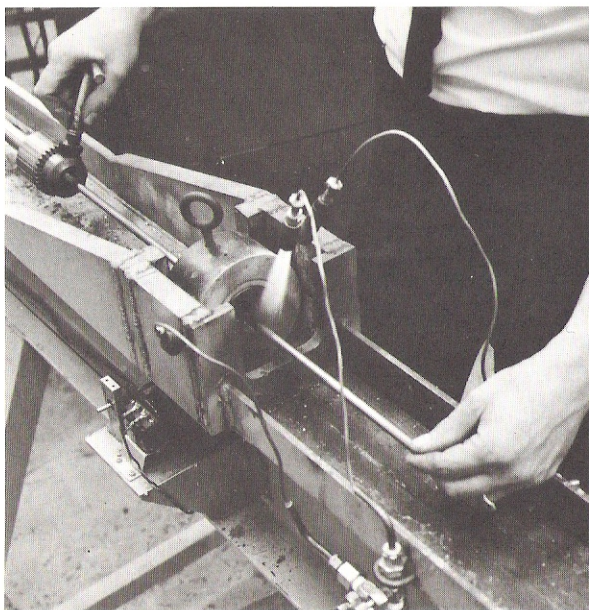
Two views of a typical example of beryllium machined at NMPO.



REFRACTORY METAL SHEET AND TUBING

Refractory-metal work at the Evendale laboratories began in 1949, when the Mo-UO₂ fuel element system was first studied. Since then, tantalum, rhenium, niobium, and other refractory metals have also been investigated.

Originally, most commercially available shapes, particularly tubing, were inadequate for AEC applications. Marked improvements were achieved in niobium and tantalum shapes by working closely with commercial suppliers and by applying a variety of quality control techniques such as ultrasonic, eddy current, and metallography. Molybdenum and tungsten alloys, however, remained unavailable at the necessary quality levels. In support of its basic refractory-metal research, NMPO



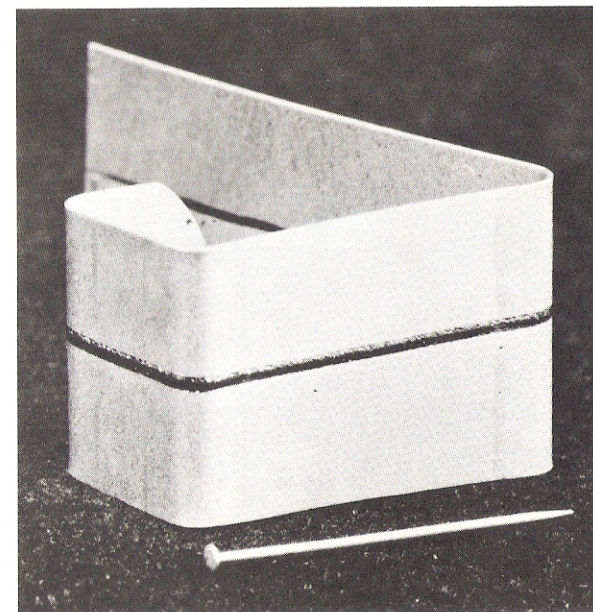
Cold-rolling ductile tungsten alloy sheet. The rolling mill is equipped with special controls as well as solid tungsten carbide rolls.

Drawing small-bore, seamless tungsten-base tubing to nuclear quality standards.

This piece of molybdenum was bent at room temperature and -60°F. Even the weldment is ductile.

personnel developed new methods to fabricate sheet and tubing of these alloys.

Using large, solid tungsten carbide rolls for sheet fabrication and special drawing equipment for tubing, NMPO laboratories are currently the primary source of special ductile tungsten- and molybdenum-base alloys. These "cold" working techniques recently led to the development of ductile tungsten-rhenium-molybdenum alloys, which show much promise in a variety of high-temperature applications. Also, high-purity molybdenum can now be welded and nevertheless retain room temperature ductility in the heat-affected zone and even in the weldment itself.



CERAMIC FABRICATION

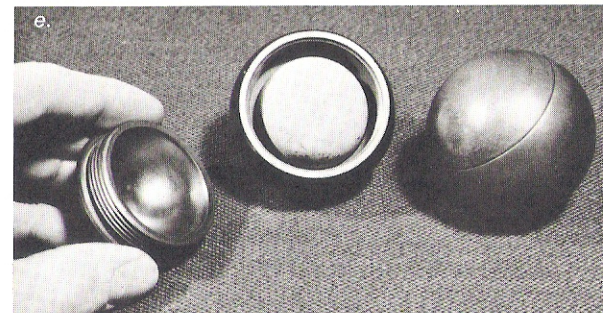
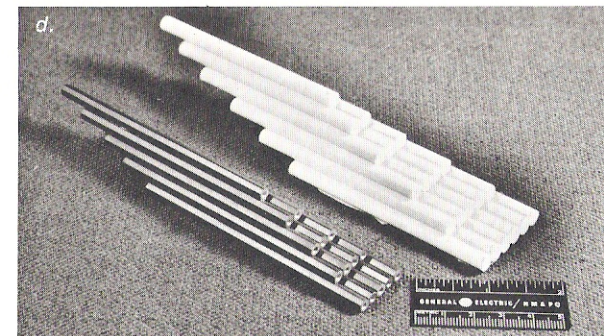
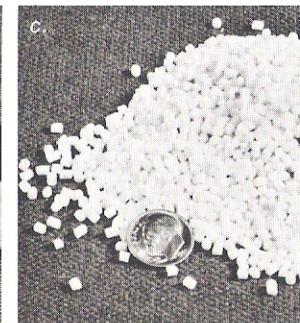
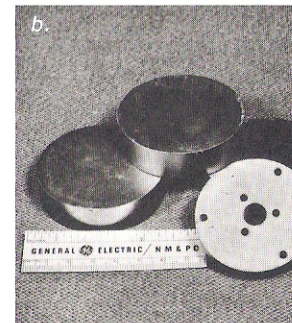
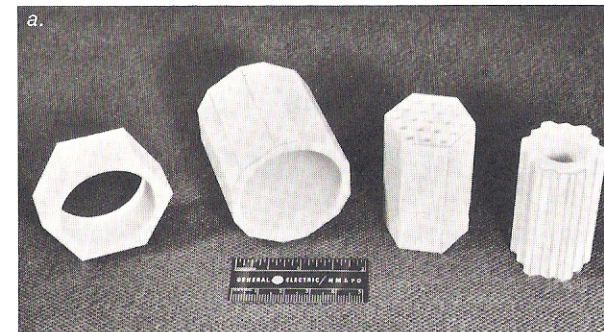
Ceramic fabrication work embraces nuclear fuels and other reactor components, as well as special products such as sheathing for high-temperature thermocouples. A composition containing UO_2 was developed that is oxidation-resistant in air at temperatures above 2700°F . Co-extrusion fabrication techniques led to a nuclear fuel tube protected by a layer of nonfueled material, while in another process, nuclear fuel balls are made in sizes up to 3 inches in diameter (for the Pebble Bed reactor); again, the fuel is clad with a nonfueled material.

High-purity BeO , WO_3 , HfO_2 , CaO , ZrO_2 , ThO_2 , and UO_2 are fabricated in various shapes for reactor components, critical experiment studies, thermocouple insulators, furnace insulation pellets, and special reactor fuel products. Fabrication processes have been developed, and trial lots produced, of UO_2 and ThO_2 for the Pu and U^{233} production at Hanford and Savannah River. Sintered ThO_2 is being produced from a dried sol-gel at a rate of 1 ton per day. Production processes for TaC and ZrC have been developed, and significant improvements made in the composition and microstructure of BeO .



The "flame curtain" automatically flares up when sintering door opens to prevent contamination of the pure hydrogen atmosphere in this ceramic sintering furnace.

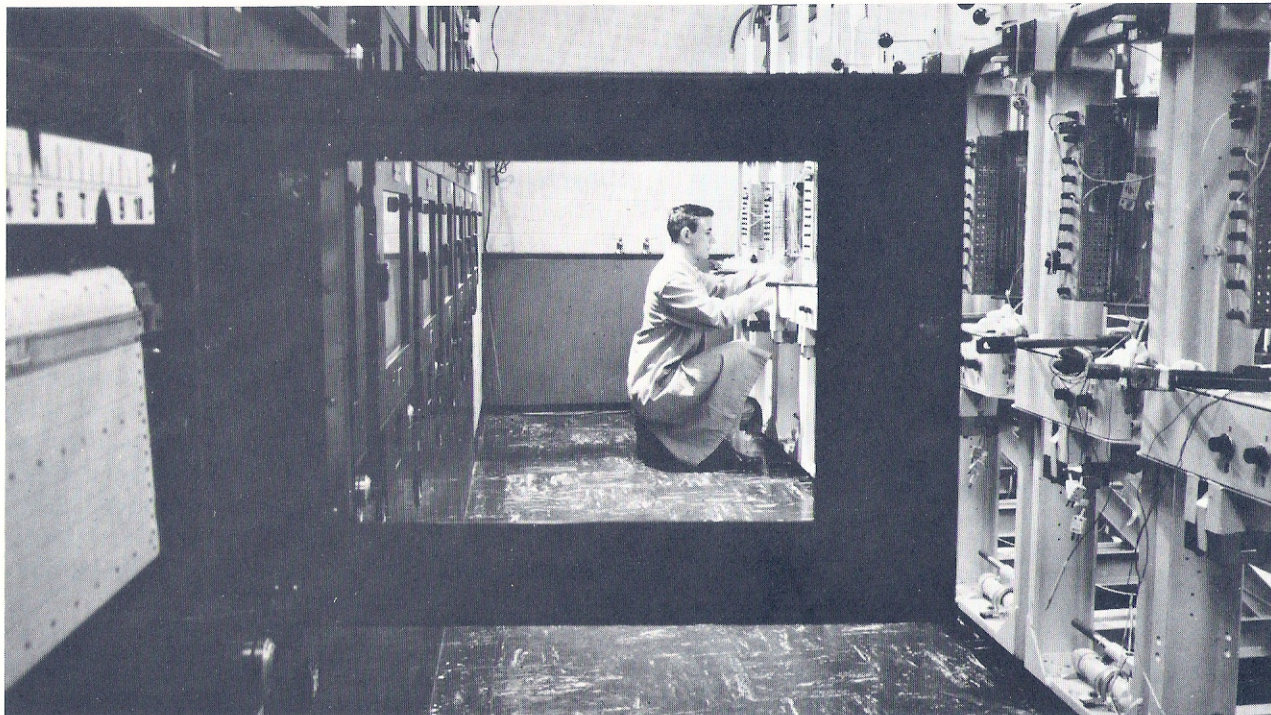
A variety of ceramic shapes are fabricated for many different applications: (a.) Precision-ground BeO nuclear reactor components. (b.) UO_2 discs used for property measurements. (c.) ThO_2 pellets for U^{233} production. (d.) Extruded BeO rods and co-extruded BeO hexagonal tubes with protective inside cladding. (e.) UO_2 - ThO_2 -fueled BeO balls clad with graphite; for pebble-bed reactors.



TESTING

Prior to use by design engineers, the properties of newly developed materials must be determined. Transmutation effects must be defined, as well as the materials' life expectancies at anticipated operating conditions (times, temperatures, and thermal cyclings). To confirm and refine the adequacy of design, "critical experiments" must be conducted; then, new reactors can be built.

An extensive testing capability has been developed at NMPO to qualify its advanced materials for nuclear applications, including central station, aerospace, terrestrial, undersea, and other uses.



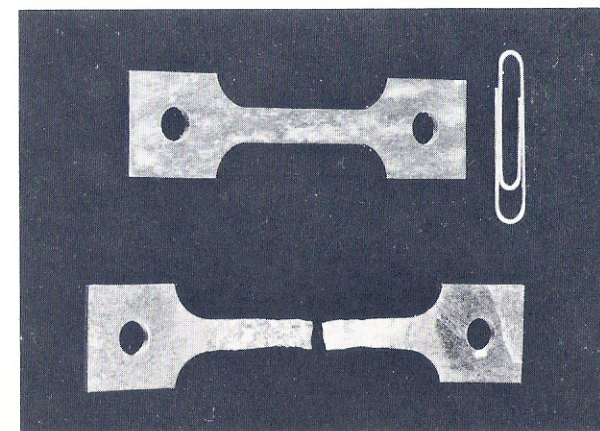
Creep characteristics of various materials are determined in these test stands which can be loaded up to 600 pounds.

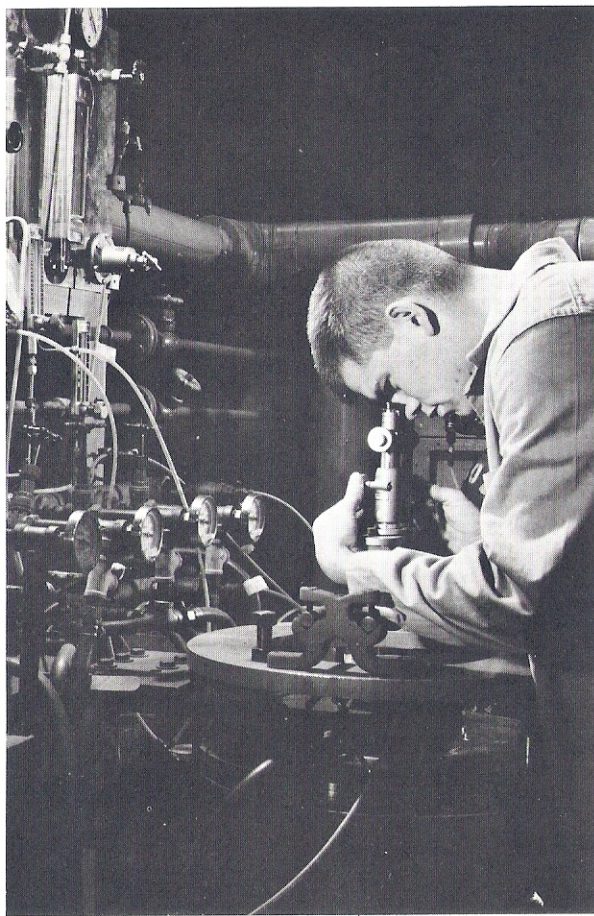
MATERIAL PROPERTY MEASUREMENTS TO 5500°F

Techniques developed by NMPO to obtain valuable material property data for metals and ceramics in reducing or inert atmospheres at temperatures up to 5500°F are now in wide use. Properties measured include thermal conductivity, thermal expansion, enthalpy and heat capacity, thermal diffusivity (to 1850°F), electrical resistivity, stress-rupture strength, creep characteristics, short-time tensile strength, hot hardness (to 2750°F), and low-cycle fatigue (to 1700°F).

These studies provide the basis for evaluating the potential usefulness of specific materials in

Typical creep-rupture specimen before and after testing.





A technician optically measures a thermal-expansion specimen; refractory metals and ceramics are tested in helium or argon at temperatures up to 4500°F.

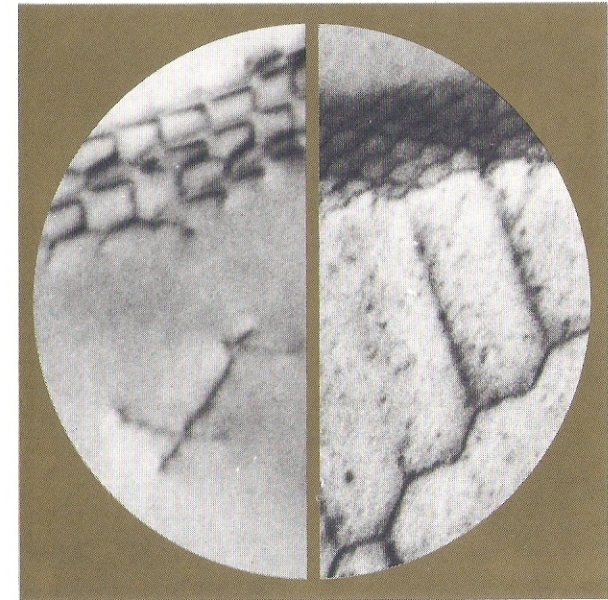
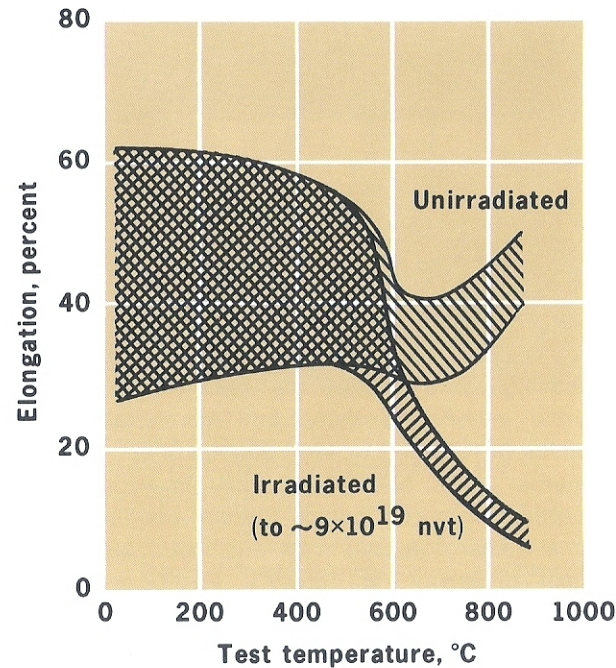
widely diverse nuclear and non-nuclear technologies. Already, these techniques have contributed to a number of projects: special programs at NASA-Goddard and Brookhaven National Laboratory, the Poodle program, and government thermionics work.

EFFECTS OF RADIATION

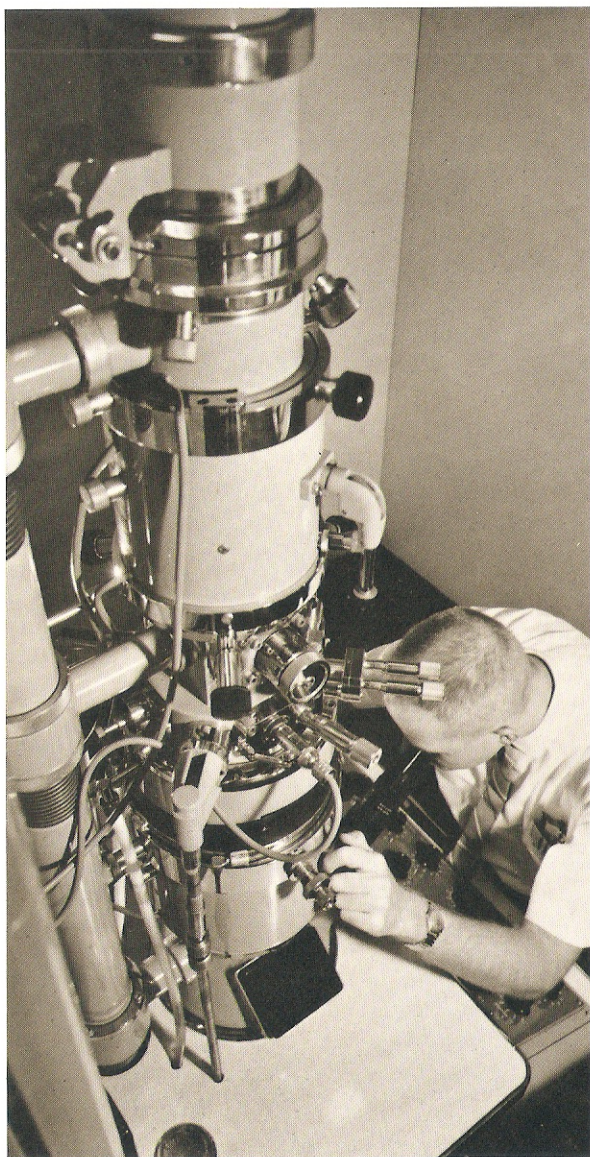
Since 1951, NMPO scientists have vigorously investigated the effects of reactor radiation on the physical and mechanical properties of materials. This research has significantly contributed to rapid progress in nuclear materials technology.

Radiation-induced changes in the properties of organic reactor moderators and coolant fluids, oils, and elastomeric materials were determined

for high-temperature reactor applications. Later studies revealed much about the influence of neutron radiation on the mechanical properties of BeO and heat-resistant alloys. The accompanying graph, for example, charts the elevated-temperature embrittlement of Hastelloy X, a widely used cladding and structural alloy, tested under controlled conditions.



Electron micrographs of unirradiated (left) and irradiated tungsten. Black dots in the irradiated sample are defect clusters caused by displacement of atoms from their normal locations. (Magnification — 100,000X)



Electron microscope, capable of magnifications up to 200,000X.

Valuable new information has also been derived for the refractory metals and their alloys, including the migration behavior of radiation-induced defects at key temperatures and the influence of transmutation products formed during irradiation. Based on these studies, NMPO is now evaluating the use of refractory metals for high-temperature service in fast breeder reactors.

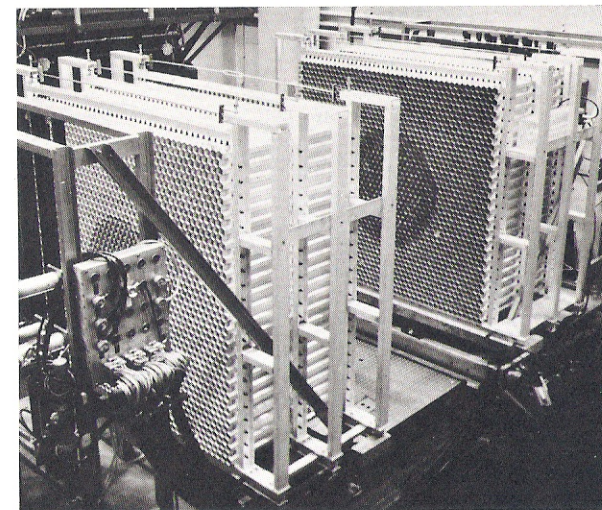
IDAHO TEST STATION

Capable of performing virtually any type of nuclear engineering measurements and proficient in design and assembly, the Idaho Test Station (ITS) contributes heavily to NMPO's research efforts.

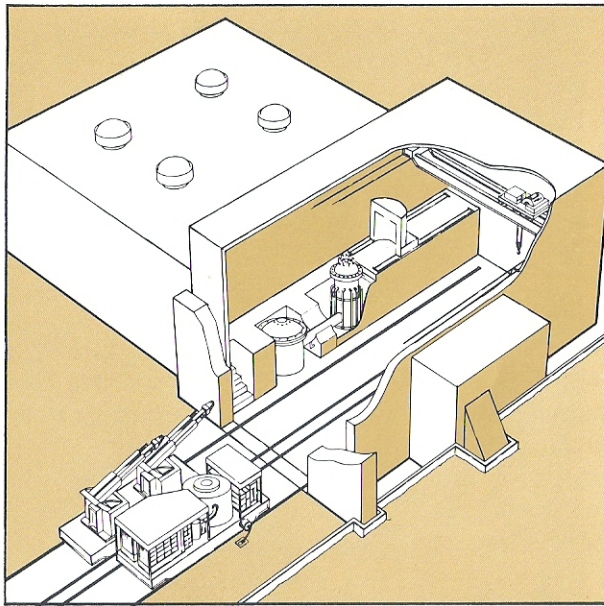
On this site, complete critical experiments and low power reactor tests are conducted on thermal, intermediate, and fast reactors with various cores, moderators, and reflectors. Standard nuclear measurements on the critical assemblies achieve a high degree of sensitivity, accuracy, and reproducibility; Rossi-alpha and pulse neutron techniques are used routinely. Much of NMPO's in-pile test work is done at ITS, including final preparation, instrumentation, assembly, and check-out of test specimens. All phases of in-pile testing and post-test handling are technically monitored.

ITS personnel are experienced in field assembly of mobile nuclear powerplant systems, including

manual and remote assembly, disassembly, maintenance, and refueling operations; they have also developed many specialized remote handling techniques. Complete test programs of reactor instrumentation and control systems are prepared and conducted, and special electronic units required in the tests can also be designed and developed.



One of two split-table test assemblies for conducting critical experiments at ITS. One side is fixed; the other is movable.



Artist's concept of the Initial Engineering Test Facility as modified to conduct performance and qualification testing of the 710 reactor. Modifications include a shielded test cell with concrete walls six feet thick, an equipment building, and several process systems.

Evaluating the safety aspects of reactor configurations and operational methods is one of Idaho's primary purposes; many safety analyses have been submitted to the AEC covering a wide variety of reactor types and applications. Radio-meteorological field experiments have been successfully designed and executed. This work required not only solution of logistics and instrumentation problems, but also the development of flexible computational techniques for studies of radioactive effluent behavior. As in all experimental work performed at ITS, pre-analyses were made so that theoretical and experimental results could be objectively compared.

ITS is preparing the AEC safety analysis report of the LOFT Program and also has responsibility for the initial critical experiment work.

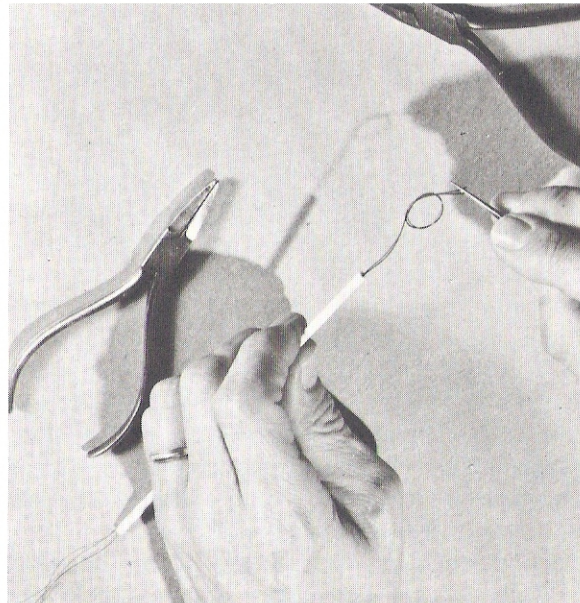
THERMOCOUPLES

High-temperature technology demands accurate, long-life temperature sensors for reducing or neutral atmospheres up to 5000°F and NMPO is engaged in developing refractory-metal thermocouples capable of meeting these extreme conditions. Tungsten versus tungsten—rhenium thermocouples have been calibrated up to 5800°F, the melting point of the tungsten—rhenium leg. Insulation and sheath materials are also being developed; recently developed components will permit the instrumentation of graphite fuel element

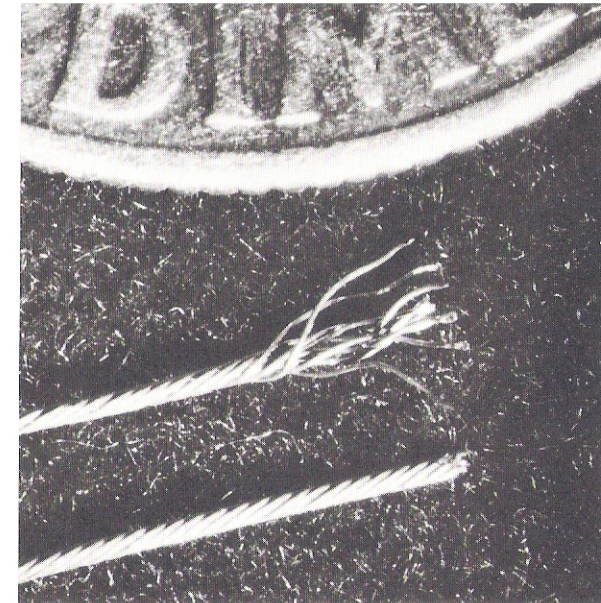
reactors at temperatures to 4500°F in a hydrogen—graphite environment.

Currently, a major NMPO goal is to provide satisfactory thermocouples for the fast breeder reactor program. New alloys being developed are stable thermoelectrically under conditions of high fast neutron dosages and the attendant transmutation of the thermoelectric alloys. In-pile evaluation of several years' duration is being conducted to obtain data for fast neutron dosages in the 10^{22} to 10^{23} nvt range.

Demonstrating the ductility of a tungsten—rhenium thermoelement, a technician knots the thin-wire, refractory-metal strands.

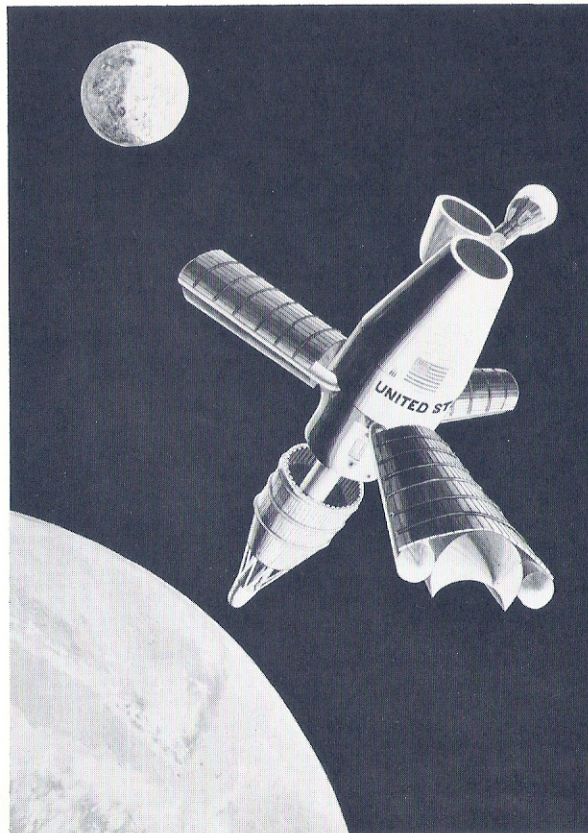


15X magnification of a stranded refractory-metal thermoelement. An ordinary dime is shown for size comparison.



710 PROGRAM— REACTOR FOR SPACE POWER GENERATION

With a solid background in the design of compact, gas-cooled reactors and a history of successful fuel element development, NMPO was selected by the AEC to perform the 710 reactor program. A fast-spectrum reactor with refractory-metal core and structure, the 710 is a highly promising new approach to the use of nuclear energy for space propulsion and power generation. Since no moderator is needed, a fast-spectrum reactor core can be smaller than that of a thermal reactor for a given power output. The smaller core, in turn, requires less shielding, the heaviest component of a nuclear system. Being smaller and lighter, and

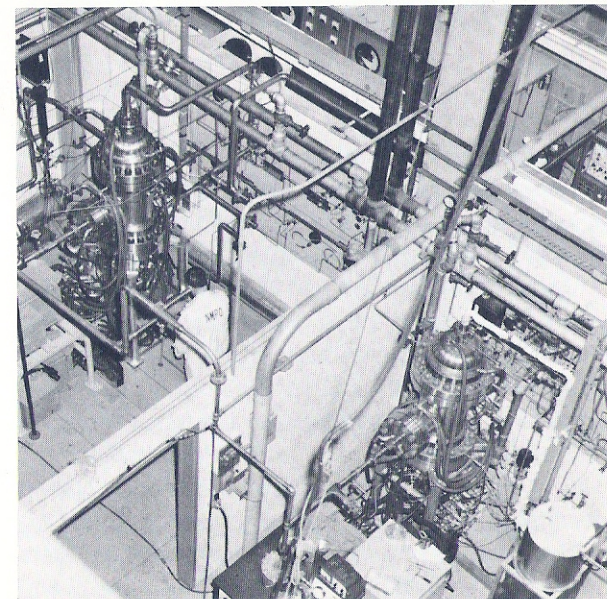


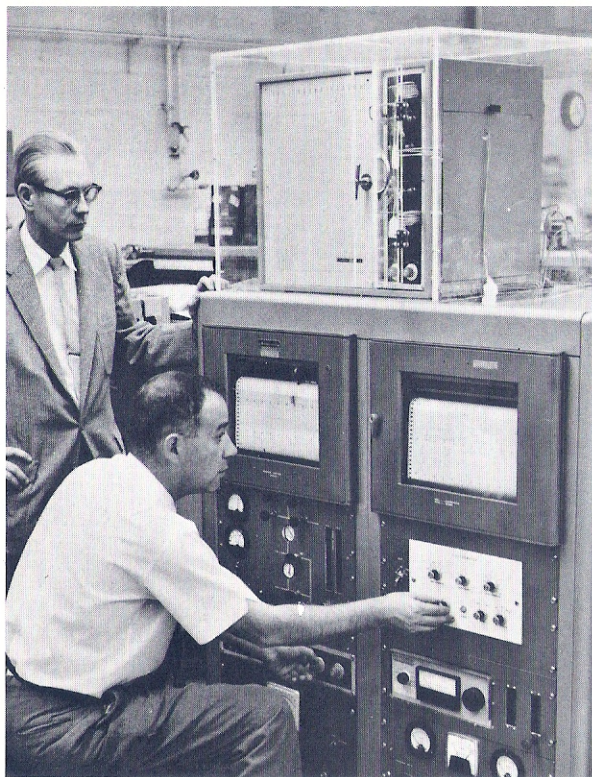
also able to operate at extremely high temperatures due to the high melting points of refractory metals, the 710 will be particularly well suited for auxiliary power generation in space where size and weight are of paramount importance.

In the early stages of the program, the basic neutronics of fast-spectrum, refractory-metal reactors were explored by NMPO nuclear engineers. These efforts made it possible to calculate nuclear characteristics with a high degree of confidence. 710 critical experiment work at the Idaho Test Station has confirmed and refined these pre-operational analyses.

Artist's concept of a manned, orbiting satellite powered by the 710 reactor.

Two-loop facility for testing fuel elements under closely controlled conditions.





Gas chromatography equipment.

A substantial amount of preliminary design work has been completed, encompassing both the space power system and also the variations required for ground test qualifications of the space system.

Current work on the 710 is primarily being devoted to development of the refractory-metal fuel elements, key to the success of the overall reactor system. Difficult fabrication processes have been mastered, and 10,000-hour qualification tests of fuel element stability and materials capability are well under way. To test the fuel elements, NMPO designed and built gas-cooled, closed-loop test facilities capable of performing 10,000-hour life tests at temperatures as high as 3900°F, pressures of 850

psi, and an inert gas flow rate of 15 cubic feet per minute; specimens can be resistively heated to simulate nuclear internal power generation. To eliminate lubricant contamination, the coolant gas is circulated by gas-bearing circulators or reciprocating diaphragm pumps. Special chromatography equipment and techniques are used to continuously measure impurities in the gas stream to levels as low as 25 parts per billion.

In other static and dynamic test programs, candidate materials and configurations are under investigation, both in-pile and in the laboratories; excellent results are being obtained.

Currently under development for a multi-hundred electrical kilowatt system, the 710 reactor is adaptable to a wide range of outputs without major modifications. In addition, its high-temperature, refractory-metal fuel element materials are applicable to Brayton, Rankine, and stationary conversion type power cycles. With such flexibility in output and cycle selection, the 710 has the potential of becoming the reactor workhorse for space power generation.

SUPPORTING SYSTEMS WORK

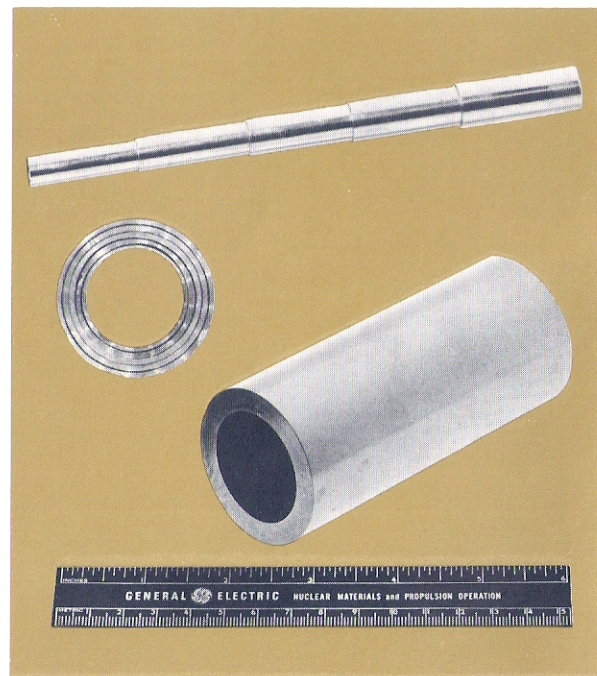
RADIOISOTOPE CONTAINERS

Although safeguards criteria impose the most stringent quality requirements upon the designer of suitable containers for radioisotopes, other problems must also be solved: compatibility (of containers with isotopes and coolants), stress analysis for high-temperature creep resistance,

sealing, and refractory-metal machining. To meet these challenges, NMPO engineers first identified the high-temperature creep characteristics of many refractory metals, and then both designed and fabricated satisfactory radioisotope containers for a number of AEC programs. Computer programs were coded to aid design analyses. Some 40 new refractory-metal brazing alloys were also developed, as well as an electron-beam pattern generator which automatically controls the weld pattern and quality in a variety of geometrical shapes.

For several applications requiring dissimilar materials on the inner and outer surfaces, NMPO has produced containers consisting of as many as five layers of dissimilar metals; solid-state diffusion bonding techniques were used in this work.

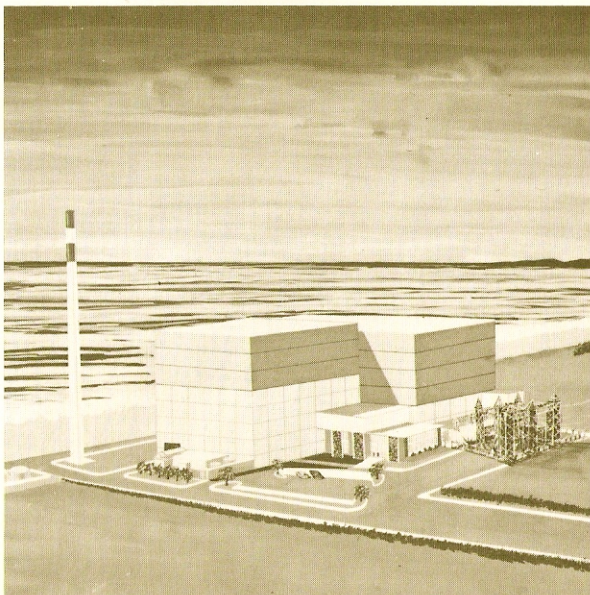
Five-layer radioisotope container prior to solid-state diffusion bonding is shown in both the "telescopic" and end views; the bonded assembly in its cylindrical form appears lower right. The two outer layers are rhenium while the inner three are a tungsten-rhenium alloy.



NUCLEAR SAFETY

Under the LOFT (Loss of Flow Test) project, NMPO is investigating (for Phillips Petroleum Company) core material behavior in a hypothetical, industrial power-producing nuclear reactor that has suffered a loss-of-coolant incident. The core is subsequently assumed to experience a thermal excursion due to nuclear activity. To study fuels under the probable thermal and atmospheric conditions of the incident, a special thermobalance was developed to measure steam oxidation of metal claddings and UO_2 at temperatures to their melting points; induction and resistance heating units were also built to heat samples of metal-clad UO_2 in steam or other atmospheres at rates up to 9°F per second.

Artist's concept of a 1000 MWe boiling water reactor.



Measurements are made of the amount of UO_2 meltdown occurring at various stages of cladding oxidation, the tensile strength of cladding materials up to their melting points, and the thermal conductivity of claddings and UO_2 .

High-temperature (1400°F) fatigue properties of reactor pressure vessel materials are also being determined in relation to the fast breeder reactor program.

COMPUTER PROGRAMMING

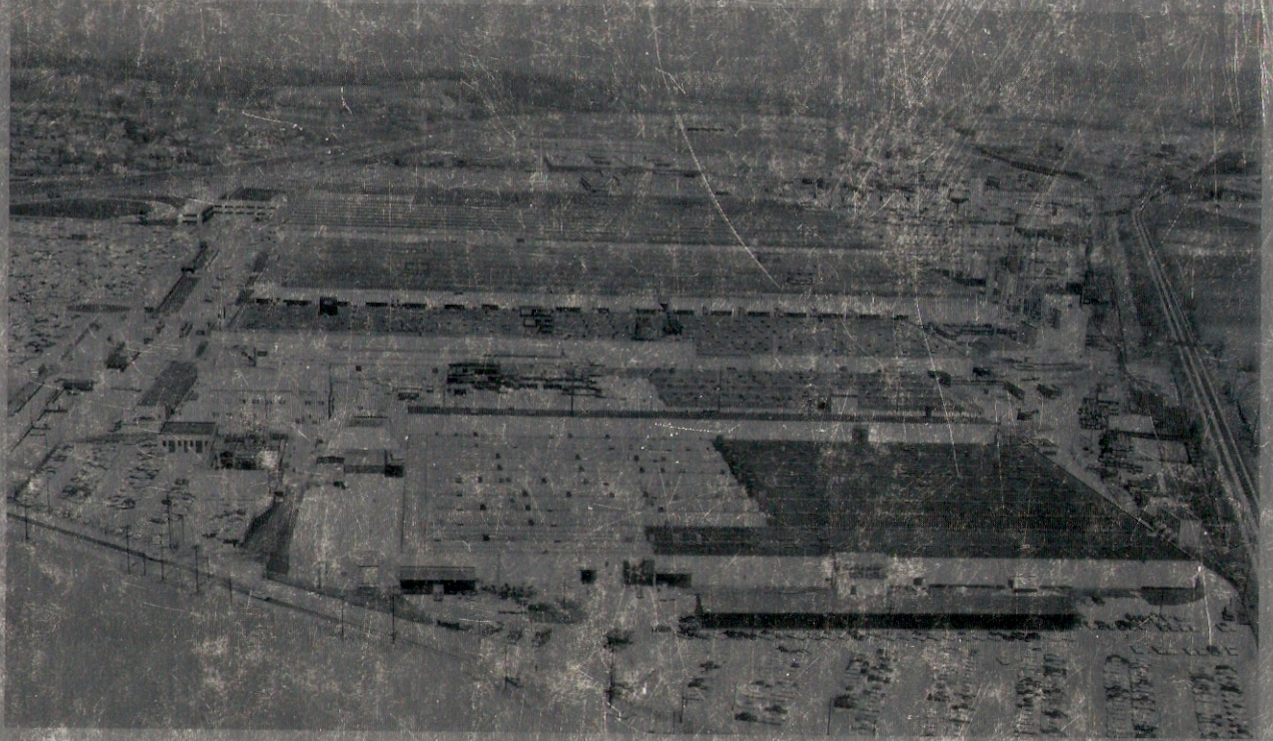
Significant and unique developments in computer programming include the THTD (Transient Heat Transfer—Version D) code which was developed for systems design studies. User-oriented despite its ability to handle highly complex problems, THTD can compute transient and steady-state temperature solutions, including conduction, convection, and thermal radiation of materials with temperature-dependent thermal properties.



This new program is being used in mission studies of the Apollo Block I command and service modules and in space simulator studies. NMPO personnel converted THTD from the GE-625 to the UNIVAC 1108 computer for use by NASA-Manned Space Center personnel. It is also in use in thermal design analyses of various turbojet engines such as the GE/4 for the SST and the TF-39 for the C5A logistics transport. Other applications include thermal analyses of LOFT reactor safety studies and various SNAP systems, and thermal balance studies for spacecraft, satellite, and re-entry conditions.

In earlier work, computer program GEORGE was developed to provide a completely automated reactor core analysis sequence. Other programs were developed or adapted for such studies as reactor slow-down and shielding design and attenuation.

Back cover: Aerial view of General Electric's Evendale complex; NMPO uses the three buildings in the center and left foreground.



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