JUN 12 1968

STATUS OF THE LOS ALAMOS NUCLEAR ROCKET PROGRAM

Franklin P. Durham
University of California
Los Alamos Scientific Laboratory

80396
CONF-680609--2

Abstract

The effort in the Rover program at the Los Alamos Scientific Laboratory during the past year has been divided between preparing for the Phoebus 2A 5000 megawatt reactor test and the development and evaluation of improved fuel elements and reactor support materials. Phoebus 2A, which is now ready for testing, has been designed for the highest power, power density, and chamber temperature in the Rover program to date. Facility modifications and checkout have been completed with a dual turbopump feed system capable of delivering 285 lb/sec of liquid hydrogen at 1300 psi. To provide a realistic environment for fuel element evaluation a small, fuel element test reactor, Pewee 1, has been designed and fabricated with a first test planned late in the year. Significant progress has been made in the development of zirconium-uranium-carbide/carbon composite fuel elements that offer the promise of longer operating life than the present graphite-based fuel elements with a modest increase in temperature. Progress has also been made in the pure zirconium-uranium carbide system that will be capable of significantly higher temperatures than the present elements for useful operating times.

During the past year the efforts in the Rover program at Los Alamos have been devoted to preparation for the Phoebus 2A, 5000 megawatt reactor test; the design and fabrication of a small fuel element test reactor, Pewee 1; and the development of improved conventional and advanced performance fuel elements and hot-end support materials. In this paper, the recent progress and status of these three topics is reviewed.

Phoebus 2A

Phoebus 2A is the largest reactor yet developed in the Rover program. In addition to operating at the highest power, it will also have the highest chamber temperature and the highest power density. The design point parameters are shown in the following table:

TABLE I PHOEBUS 2A PARAMETERS

Power	5000 MW
Flow Rate	285 lb/sec
Chamber Temperature	4500°R
Chamber Pressure	625 psi
Core Pressure Drop	160 psi

The design features include a separate coolant circuit for the core support system, a redesigned reflector system in which only the poison plates rotate for neutronic control, high power density fuel elements, and a new high-performance Hastelloy X nozzle developed by Aerojet. In addition, the dual

Mark 25 Rocketdyne turbopump feed system will be used on a reactor test for the first time.

A series of cold-flow tests were completed on a geometric mockup of the reactor last summer. The primary purpose of these tests was to study facility and reactor heat capacity interactions during the startup transient and chilldown when liquid hydrogen is introduced into the system. In addition, gaseous hydrogen flows of up to 70 lb/sec verified the structural integrity of the design as well as its flow and pressure drop characteristics.

A number of minor design changes have been made on the final reactor configuration as a result of these cold flow tests. These changes were primarily in the area of improving a number of pressure-vessel seals. In addition, the flow circuit to the main pressure-vessel closure was changed to increase its chilldown rate during the startup transient.

Following the cold flow tests a number of facility experimental plans have been completed to demonstrate the capability of the feed system and emergency shutdown systems to perform adequately under simulated reactor operating conditions as well as under conditions of possible malfunctions.

The dual turbopump feed system has been endurance tested at the Phoebus 2A design point as well as operated under steady state conditions of 35,000 rpm, 380 lb/sec flow rate and 1500 psi discharge pressure with a resulting calculated shaft horsepower of 44,000. During the malfunction tests, the pump operation has repeatedly been shutdown abruptly from the design operating point with no damage to either pump including cases where stall has occurred on both pumps. Figure 1 shows the pump map for a normal startup to design conditions (heavy line) and a typical emergency shutdown (light line).

Figure 1 - Pump Map for Normal Startup to Full Power Followed by Emergency Shutdown

Ref

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Most of the time and effort in the facility experimental plans has been associated with the operation of the emergency shutdown coolant system consisting of a high-pressure, 7,000 gallon liquid hydrogen dewar and related plumbing which floats on the main line at a specified pressure below the operating pressure. The very high flow rate of the reactor coupled with a large reactor internal volume present a particularly difficult nozzle cooling requirement during the first half a second following an emergency shutdown before flow is established from the high pressure dewar. During this time interval the decay characteristics of the large reactor internal volume upstream of the core tend to hold up the core and nozzle chamber pressure and flow rates while the nozzle inlet pressure and flow rate tend to drop more rapidly due to the decay characteristics of the main propellant line. As a result, the nozzle coolant-side flow rate may drop to such a low level compared with the chamber-side flow rate that nozzle burnout may occur within milliseconds and before the high pressure dewar flow is established. In addition, the reverse-flow which accompanies the closing of the turbopump and turbine energy source check valves can lead to a serious pressure oscillation problem that can also momentarily starve the nozzle.

A successful procedure has been worked out during the facility tests which involves utilizing a part of the stored energy in the pump coupled with the action of a small gas accumulator on the main line and limiting the maximum opening of the pump bypass valves. Malfunctions of the following components have been simulated with acceptable nozzle flow rates resulting: a) Turbine control valve failed closed, b) Turbine control valve failed open, c) Pump bypass valve failed open. Figure 2 shows the calculated ratio of nozzle flow to chamber flow for the turbine valve failed closed malfunction test. A minimum ratio of 0.31 is acceptable from the standpoint of preventing nozzle burnout.

Figure 2 - Nozzle Flow Ratio for Emergency Shutdown with Turbine Valve Close

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission
 A. Makes any warranty or representation, expressed or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or
 B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
 As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Considerable time has also been spent in establishing reliable procedures for chilling and maintaining a chill on the high pressure dewar propellant line and in determining the dewar ullage volume buildup and blowdown flow characteristics.

The final full scale facility test was completed on March 20, and the new reactor shield was installed and flow tested before bringing the reactor to the test cell on April 9. Figure 3 shows Phoebus 2A at the test cell with the reactor shield retracted.

Figure 3 - Phoebus 2A and Shield

A series of four experimental plans are scheduled for the reactor in the period from May 15 to June 19. The first two experimental plans are concerned with calibrating the neutronics power system, flowing up to 30 lb/sec of gaseous hydrogen to check the pressure instrumentation, and bringing the reactor up to about 1000°R on neutronic power to check the core material and fluid temperature instrumentation. In addition, all facility systems will be exercised with the reactor critical and in power control to determine if there are any electrical interactions with the neutronics system that might lead to an inadvertent reactor scram. The third experimental plan will be a major test. The reactor will be brought to an intermediate power of 2170 megawatts, a flow rate of 195 lb/sec, and a nozzle chamber temperature of 3000°R to obtain steady-state data for checking design calculations and total system performance. A controls dynamics and mapping experiment will be performed on the shutdown profile.

The final experimental plan has the primary objectives of demonstrating the capability of the reactor and test system to operate at the design conditions and to operate at this condition for a

maximum of 20 minutes to obtain endurance information on the fuel elements and structural components. An important controls dynamics experiment will also be performed at full power operating conditions. Twenty minutes of operation including the planned slow startup will use most of the 1,000,000 gallons of hydrogen available. Further endurance testing is not planned since the Phoebus 2A fuel elements, some of which were manufactured over two years ago, are well below the quality of present-day elements from the standpoint of corrosion resistance.

Pewee 1

While electrically heated hydrogen flow tests are the principal tool in fuel element evaluation in the Laboratory, the electrical simulation of nuclear heating and reactor environment has many deficiencies. The desire for a realistic reactor environment for fuel element evaluation that is both economical and has a short fabrication and test cycle has led to the development of the Pewee fuel-element test bed reactor at Los Alamos. This small reactor utilizes full-scale Phoebus or NERVA fuel elements operating at the same power and flow per element as in the larger reactors but contains only one-tenth the number of elements as Phoebus 2 and one-fourth the number of elements as the NRX reactors. The method of axial and lateral core support is similar to the larger reactors.

The final design and fabrication of the first of these reactors, Pewee 1, has taken place during the past year; and the reactor is currently undergoing criticality tests prior to final assembly, at Los Alamos. The reactor core contains the latest state-of-the-art fuel elements from both Los Alamos and the NERVA contractors, as well as the new carbide-carbon composite hot-end support materials discussed later in this paper. Figure 4 shows the nuclear mockup of Pewee 1 with the core removed from the reflector.

The major operating parameters are listed below:

TABLE II

PEWEE 1 MAJOR DESIGN POINT PARAMETERS

Power	500 MW
Fuel Element Flow Rate	27 lb/sec
Fuel Element Exit Temperature	4600°R
Core Pressure Drop	190 psi
Core Exit Pressure	625 psi

The reactor design has made use of both available hardware and previous design and development experience from the Rover program. The reflector contains beryllium sectors and control rods left over from the Kiwi program. The nozzle is a scaled-down version of the NRX nozzles, and the pressure vessel is similar to previous pressure vessels except that the aft section is made from a one-piece forging, rather than being welded. A previously used test car will be used, except for the actuator shield which has been redesigned. The Phoebus 1B, 360° shield will again be used.

Figure 4 - Pewee 1 Nuclear Mockup

A modified Rocketdyne pump, the Mark 35, will be used, in which the blades have been shortened to reduce the flow rate. No major facility modifications are anticipated.

Final assembly of the reactor is scheduled for July and August leading to a full power test in November. The present plan is to run three full power cycles of twenty minutes each to demonstrate both endurance and the ability of the fuel elements to recycle.

Fuel Element and Materials Development

A major part of the nuclear rocket program at Los Alamos is in the area of fuel element and materials development. New niobium carbide coating techniques have been developed during the past year that have greatly improved the corrosion resistance of the conventional graphite elements. In addition new materials have been developed for structural support of the elements at the high-temperature end of the core. These materials are carbide-carbon composites having a basically carbide structure. The carbides used in the composites are NbC or TaC or a solid solution of NbC and TaC. These materials have excellent high-temperature strength and creep properties. Figure 5 shows the compressive creep characteristics at 2000 psi for a typical sample.

While these materials, like graphite, must be coated to protect against carbon loss, their main virtue is that even if some carbon loss does occur, they do not lose their structural integrity. Their principal disadvantage is that because of their high modulus of elasticity and thermal expansion coefficient they are more susceptible than graphite to thermal

Figure 5 - Deformation of Typical NbC-TaC Composite Support Material

stress cracks during the reactor startup and shutdown transients. This disadvantage can largely be overcome by careful attention to design and it is believed that composite support components will both increase the reliability and ultimate operating life of the Rover reactors.

In addition to investigating methods for improving the operating life and temperature capabilities of graphite based fuel elements, two new fuel element materials are under development. These are UC-ZrC-carbon composite and UC-ZrC with all free carbon removed. The former are referred to as "composites" and the latter are referred to as "carbides". ZrC is the only high temperature carbide with a low enough neutron cross section to be nuclearly compatible with the present class of epithermal reactors. Fortunately, its mechanical and thermal properties are competitive with other high-temperature carbides. Some of the properties of these materials are shown in Figures 6, 7 and 8.

Figure 6 - Deformation of Typical UC-ZrC Composite

Figure 7 - Elastic Modulus of Typical Materials

Figure 8 - Tensile Strength of Typical Materials

* The composite fuel elements offer the same structural advantages as the composite support materials. They also offer the promise of lower carbon loss than graphite as a function of time and temperature. Because of the free carbon in the matrix, a eutectic melting point of about 5500°R places a practical limit for reactor design of about 5000°R fuel element exit gas temperature.

The disadvantages of the composites are that they have a factor of two higher density than graphite and they have a maximum power density limit that is lower than graphite because of their susceptibility to thermal stress cracks. Since thermal stress considerations have not limited the power density of graphite fuel elements in reactor designs to date, the thermal stress characteristics of the composite elements may be adequate for power densities of interest. Fuel element samples of this material will be included in the Pewee 1 reactor.

The uranium-zirconium-carbide material with no free carbon appears to be the highest temperature material of practical interest for fuel elements. Preliminary experiments indicate fuel element exit temperatures of 5500°R or higher may be possible with this material. Its high density and difficulty of manufacture lead to its consideration for application in a segmented element where only the highest temperature section at the exit end is made of the carbide. As can be seen from Figures 7 and 8, the ratio of modulus of elasticity to tensile strength is higher for the pure carbide than for the composite, indicating a lower tolerance to thermal stress than for the composites. The difficulty of manufacture and testing of this material will require a longer development time than for the composites. The results to date indicate the effort to be worthwhile because of its high temperature capability.