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TITLE Assessment of a Hot Hydrogen Nuclear Propulsion Fuel Test Facility

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# ASSESSMENT OF A HOT HYDROGEN NUCLEAR PROPULSION FUEL TEST FACILITY

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## Abstract

Subsequent to the announcement of the Space Exploration Initiative (SEI), several studies and review groups have identified nuclear thermal propulsion as a high priority technology for development. To achieve the goals of SEI to place man on Mars, a nuclear rocket will operate at near 2700K and in a hydrogen environment at near 60 atmospheres. Under these conditions, the operational lifetime of the rocket will be limited by the corrosion rate at the hydrogen/fuel interface. Consequently, the Los Alamos National Laboratory has been evaluating requirements and design issues for a test facility. The facility will be able to directly heat fuel samples by electrical resistance, microwave deposition, or radio frequency induction heating to temperatures near 3000K. Hydrogen gas at variable pressure and temperatures will flow through the samples. The thermal gradients, power density, and operating times envisioned for nuclear rockets will be duplicated as close as reasonable. The post-sample flow stream will then be scrubbed and cooled before reprocessing. The baseline design and timetable for the facility will be discussed.

## 1. INTRODUCTION

As one of the key national laboratories involved in the Space Exploration Initiative Los Alamos is charged with advancing several technologies critical to the success of SEI. One of these, nuclear thermal propulsion, has been identified by the Stafford Synthesis Group as necessary for safe and cost effective exploration of the Moon and Mars.

Los Alamos National Laboratory first began nuclear rocket research during the ROVER Program from 1955 to 1971. Los Alamos has recently been designated as the DOE Project Office for Nuclear Propulsion Technology. The primary emphasis is fuels and materials development. We will consequently evaluate a large variety of fuel materials (UC, ZrC, $UO_2$, etc.) and geometries in support of the National Nuclear Propulsion program. Over the near to intermediate term significant advances in technology will be required to assure reliable and safe operation at the elevated temperatures. The purpose of this study is to assess what kinds of tests and facilities will be required to achieve the goals of the nuclear thermal propulsion technology program. We will restrict our discussion, not to full scale testing of reactors, but more in the near term research and development phase and in the mid term where safety and risk reduction for the full-scale tests will be a prime consideration.

## 2. SEI NUCLEAR THERMAL ROCKET REQUIREMENTS

The current development strategy is for a modest increase [1-3] in performance requirements over those in the ROVER/NERVA Program. Typical manned Mars NTR propulsion requirements are:

| | |
|---|---|
| Thrust, nominal | 890 kN |
| Specific Impulse | > 900s |
| Maximum Operation Time | 4.5 hr |
| Stagnation Temperature | > 2700K |
| Stagnation Pressure | > 60 atm |

Compared with a chemically propelled system these performance conditions for a nuclear rocket will dramatically reduce the required ship mass in low earth orbit.

## 3. ENVIRONMENTAL COMPLIANCE IN TODAY'S ENVIRONMENT

With today's requirements for environmental compliance the testing and characterization of fuel elements and subassemblies under non-fissioning conditions, much less testing full reactor cores under operational conditions, can be a very daunting task [4]. Our approach will be a graded one with a gradual increase on scale and complexity (Figure 1). Near term testing capabilities will include erosion/corrosion tests on small samples in open test chambers with optical access for optical and laser diagnostics with hydrogen flow heating capability up to 200Kw. Intermediate-term testing capability (3-10 years) will include the ability to test full-length fuel elements with heating capability up to 2 Mw at pressures greater than 60 atm. Our assumption is that the initial testing of reactor elements will be carried out near populated areas as opposed to full-scale fission testing, which will invariably take place in remote areas such as the Idaho National Engineering Laboratory or the Nevada Nuclear Test Site. Some of the technical issues of full-scale fission tests have already been discussed in Reference 4. All testing through intermediate-term will be carried out with depleted U fuel elements. Because of environmental and safety requirements it will take some time (up to seven years) before we can come up to even the testing capabilities achieved in the Los Alamos ROVER days.

## 4. TESTING REQUIREMENTS

The requirements for high temperature and pressure in the reactor core over long operating times necessitates a significant development effort in fuel elements in the near future if program schedules are to be met. Technical issues of greatest concern are fuel element erosion/chemistry, variation of thermal expansion rates, compressive deformation, flexure and tensile strengths, and thermal stress fracture.

The goal of the intermediate-term testing facility is to include the ability to test full-length fuel elements. The ROVER testing furnaces had the following standard conditions [5]:

| | |
|---|---|
| Heated length of element, cm | 120 |
| Hydrogen flow, kg/hr | 85 |
| Power, kW | 850-1400 |
| Exit Gas temperature, K | 2500-2800 |
| Inlet/Exit gas pressure, atm | 40/30 |

The facility requirements over the intermediate term (3-10 years) are a modest extension of the ROVER testing capabilities:

- 1-2 Mw flow enthalpy for fuel characterization of single fuel elements. The method of heating the hydrogen is left as an option.
- Flow rate of 20g/s $H_2$ at $T_o > 2700K$, $P_o > 1000$ psi. Up to four hours of test time.
- Depleted uranium fuel elements.
- Open cycle hot hydrogen with flaring of the exhausted hydrogen and scrubbing or closed cycle with heat exchanger and filtering to remove contaminants.

In addition to its primary function, the facility should have laboratory space for diagnostics development and innovative concepts, as well as being a user facility for industry. On the other hand, because of safety considerations in the handling of hot hydrogen, this facility cannot be everything to everybody.

Because higher operating temperatures are required to achieve higher specific impulse, accelerated fuel erosion/corrosion at the higher temperatures will be a major near to intermediate term issue. The comprehensive ROVER Program testing included much full-length fuel element testing under changing conditions of composite material, volume % uranium, temperature, exposure time, and thermal cycling [6]. The standard method of measurement of erosion/corrosion was primarily a post-mortem measurement of the mass loss of the fuel element. Surface temperatures were measured using optical pyrometry. Recent advances in non-intrusive diagnostics will complement these well-established measurements. Near-term plans call for use of laser induced fluorescence diagnostics to measure real time gas evolution in the boundary layer between the fuel element and the hydrogen flow stream. Figure 2 shows the gas phase equilibrium concentrations of potential volatiles as a function of temperature for a ZrC pellet we will be testing in the near future. We are currently pursuing techniques to measure the rate of evolution of some of these gases. As the program develops we will be developing hydrogen molecule and atom diagnostics for determining temperature, density, velocity and the degree of association in supersonic flows [7].

## 5. HOT HYDROGEN FACILITY

Figure 3 shows a rough schematic of medium-term facility operating parameters. Because of the environmental requirements discussed above we are initially considering a closed-loop continuously running system. The primary components of the system are the fuel element and its heater system, heat exchanger, HEPA filter, compressor, refrigerator, cold trap, a secondary compressor, and heater.

The fuel element heating system is at the heart of the closed loop system. Although resistive heating of the fuel element was quite successful in the ROVER experiments, there were problems of gripping and breakage of the ends at the higher temperatures [5]. Moreover, the thermal load of a resistively heated fuel element is quite different from that in a fissioning reactor (Figures 4 and 5). Consequently, we are examining alternative techniques in simulating the thermal loads on a fuel element. Very shortly we will investigate the use of Radio Frequency (RF) inductive heating of fuel elements to simulate thermal loads in a reactor. Eventually, we will investigate combining RF induction heating with resistive heating to better simulate the thermal loads.

## 6. CONCLUSIONS

We have developed a conceptual design for a facility devoted to testing and characterizing fuel elements for the SEI/Nuclear Thermal Rocket. Although the environmental and safety requirements for a testing facility of this type are extremely demanding, a phased approach in scaling to large systems will provide sufficient risk reduction for orderly planning and approval of the design.

## Acknowledgements

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## BIOGRAPHICAL INFORMATION

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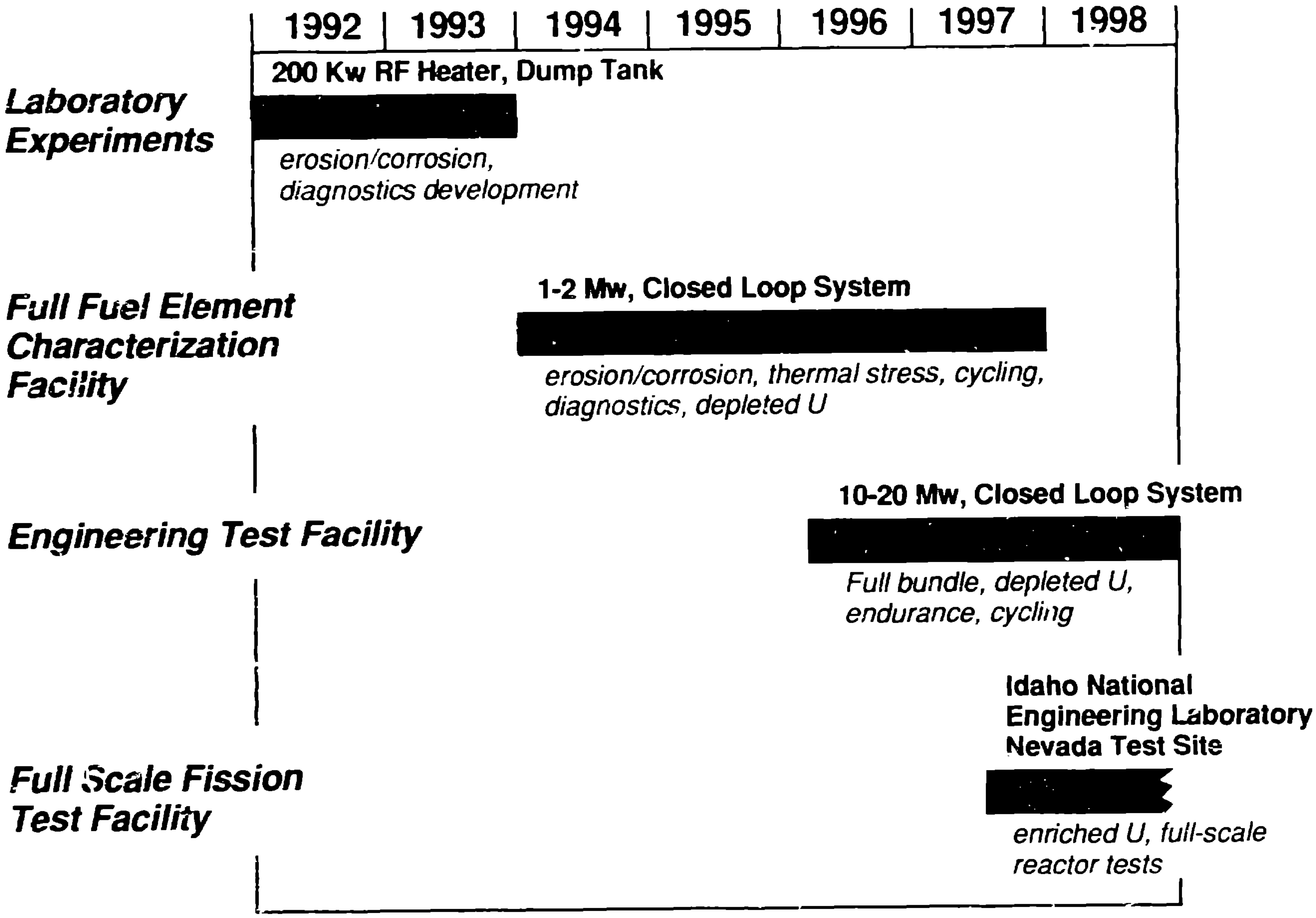

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Fig. 1. Time table for facilities development

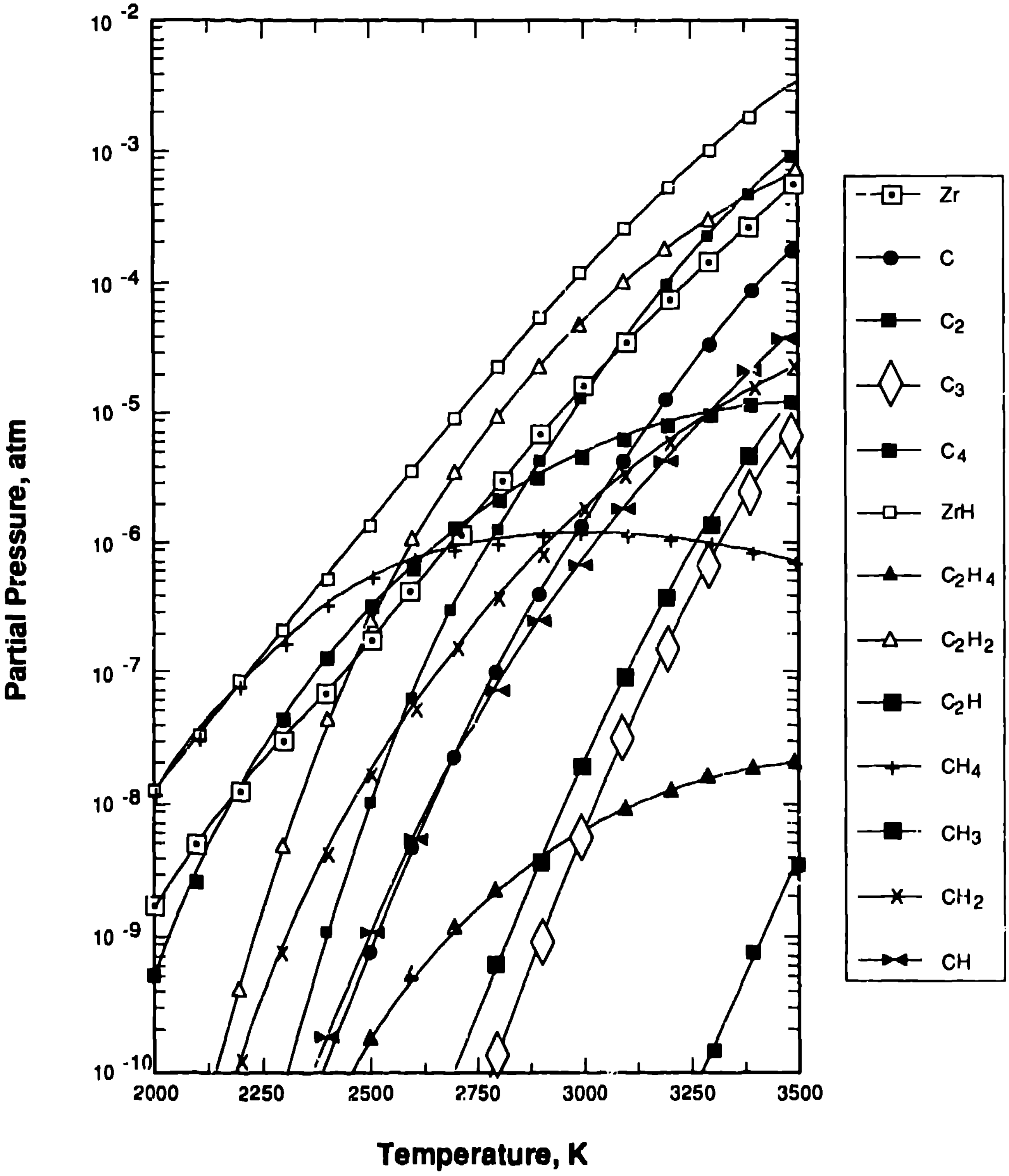

Fig. 2. Equilibrium vapor pressures for ZrC in the presence of one atmosphere $H_2$.

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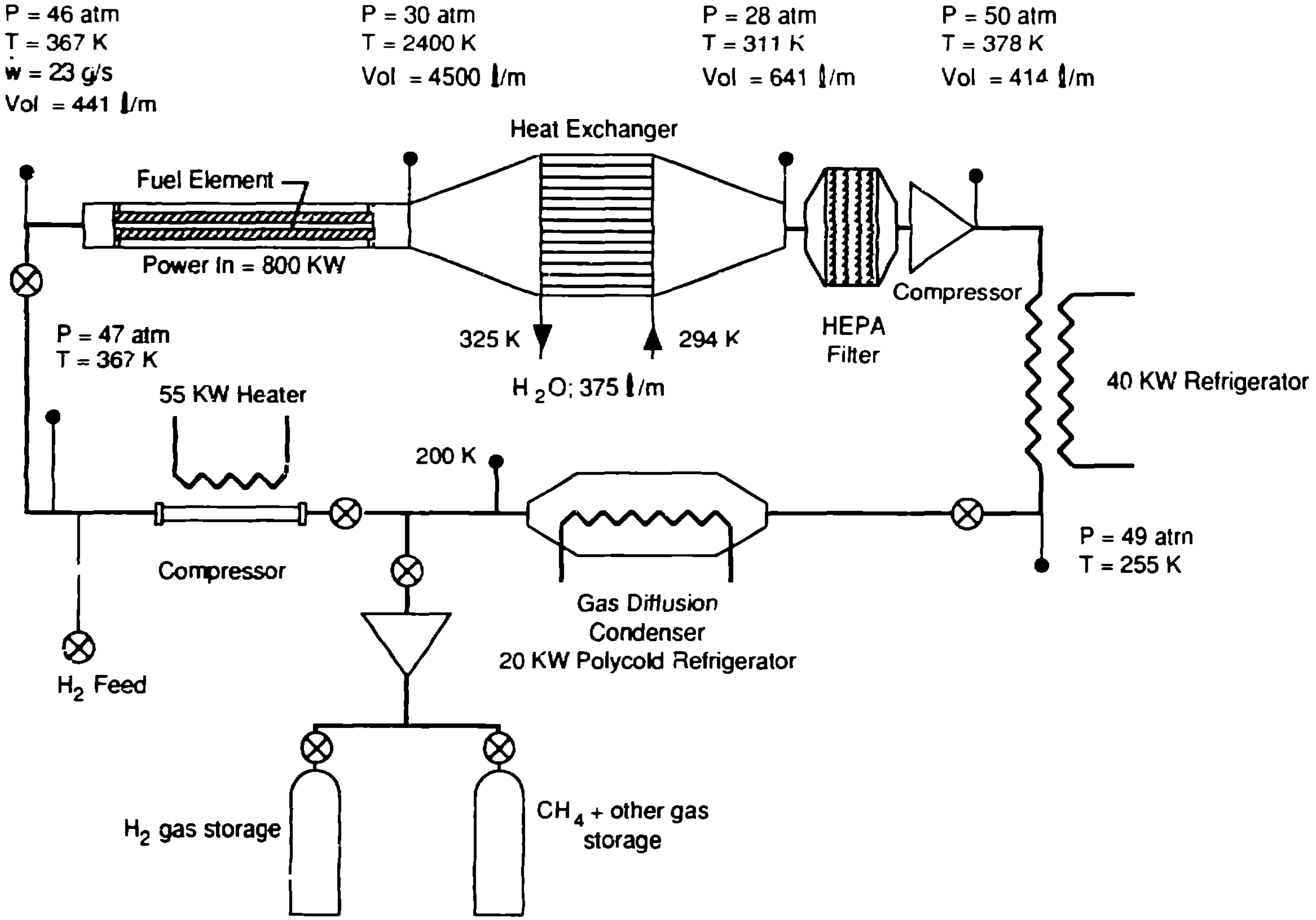

Fig. 3. Conditions for full element tests.

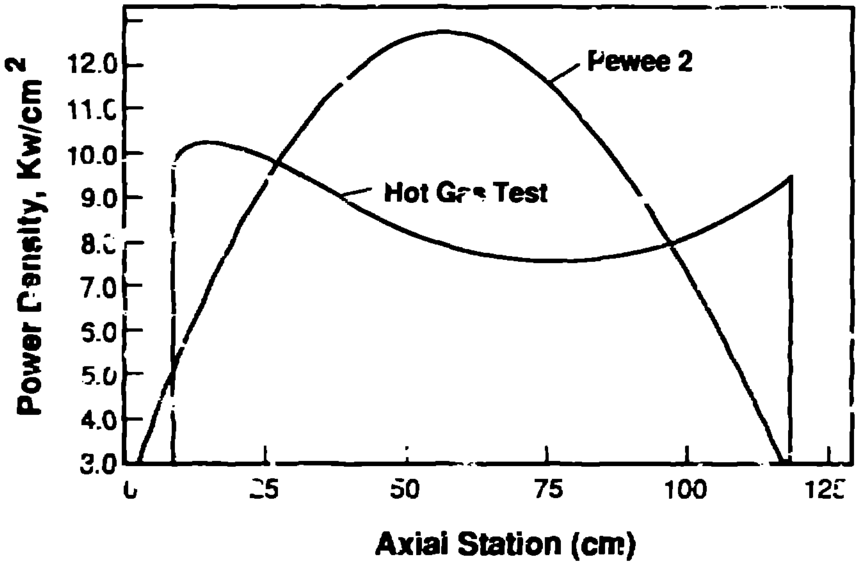

Fig. 4 Comparison of power-density generated in Pewee 2 fuel elements in the reactor and in electrical corrosion tests.

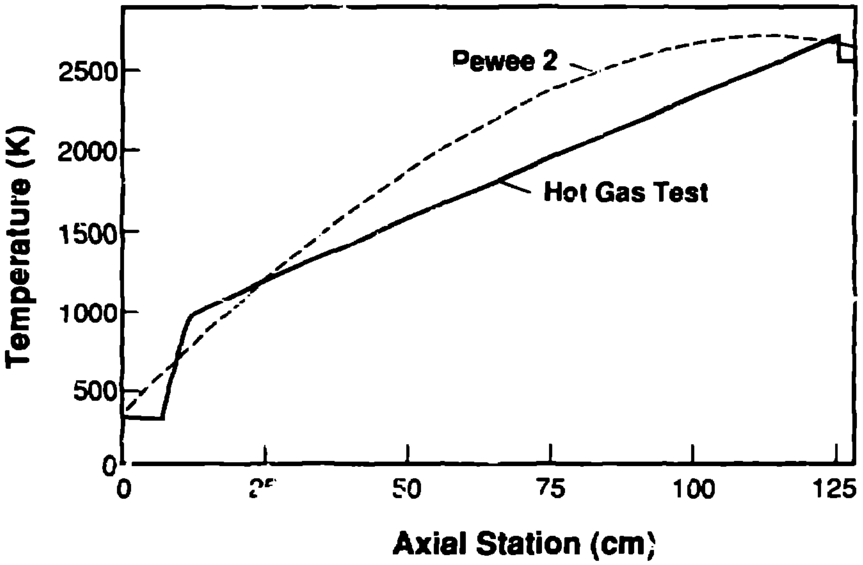

Fig. 5. Bore wall temperatures of Pewee 2 fuel elements in reactor and in electrical corrosion tests.

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