Realistic Development and Testing of Fission Systems at a Non-Nuclear Testing Facility

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Abstract. The use of resistance heaters to simulate heat from fission allows extensive development of fission systems to be performed in non-nuclear test facilities, saving time and money. Resistance heated tests on a module has been performed at the Marshall Space Flight Center in the Propellant Energy Source Testbed (PEST). This paper discusses the experimental facilities and equipment used for performing resistance heated tests. Recommendations are made for improving non-nuclear test facilities and equipment for simulated testing of nuclear systems.

INTRODUCTION AND BACKGROUND

The discovery of fission was reported in February 1939. On December 2, 1942 the world's first self-sustaining fission chain was realized at the University of Chicago. Fission reactors have since been used extensively by the Navy (powering submarines and surface ships) and the commercial power industry (20% of US electricity provided by fission reactors, much higher percentage in other countries). Operating experience in the US alone totals thousands of reactor-years.

The potential for using space fission systems to open the solar system to extensive exploration, development, and settlement has been recognized for decades. However, despite numerous US programs aimed at developing and utilizing fission systems, the only US flight of a fission system occurred over three decades ago on April 3, 1965 (SNAP10A). Although the Former Soviet Union (FSU) successfully utilized over 30 fission systems in space, all US programs since 1965 have failed to fly.

Previous space fission system development programs have failed primarily because of heavy reliance on nuclear testing for system development and because of pressure to develop systems that serve every potential customer or mission need. Heavy reliance on nuclear testing increases cost and makes it very difficult to achieve significant milestones early in a program. Recently, there has been great interest in first-generation flight demonstrator concepts whose main purpose is to demonstrate space fission systems which can be developed and utilized safely in an affordable and timely fashion. A successful first-generation flight demonstrator would address many of the programmatic and technical issues associated with the use of space fission systems. Lessons learned, technical issues resolved, and the data gathered from a first-generation flight demonstrator would be used in the design of the second and third generation systems. If fission systems are to be utilized for any flight program in the US, the next fission flight system must be safe, simple, robust and inexpensive to develop. Technology risks must be kept at a minimum, development and utilization should be inexpensive and timely, and the experience from existing nuclear databases should be utilized. This would mean that no new nuclear development would be required for full confidence in a flight demonstrator, thus, development challenges (if any) would be related to thermal-hydraulics, structures, and "balance-of-plant".

Benefits of a Simulated Nuclear Ground Test Program

Inexpensive development of fission systems can be accomplished through a strong non-nuclear ground test program.

- All non-nuclear ground tests are directly applicable to nuclear system development
- Technology issues can be demonstrated/resolved faster and cheaper with ground based hardware testing rather than paper studies.
- Program success does not hinge on performing nuclear testing. Issues can be resolved and program paybacks can be discovered long before a nuclear test has to be performed.
- Robustness of the system can be demonstrated. This results in a high confidence of the probability of flight success.
- Realistic margins of safety can be established through failure testing with no "nuclear" issues involved.
- Significant milestones can be achieved within modest budgets and schedules.
- Significant technical progress can be made with minimal risk of being "squashed" politically.
- Extensive tests can be performed on an actual flight unit.

NON-NUCLEAR TEST FACILITIES AT MSFC: THE PROPELLANT ENERGY SOURCE TESTBED (PEST)

At the Marshall Space Flight Center in Huntsville, Alabama, simulated nuclear testing is being conducted with a refractory metal module in the PEST. The first test article to operate in the PEST is the Module Unfueled Thermal-hydraulic Test (MUTT) article. This test article, a 2 inch diameter, 17.75" long pure tungsten "block", represents a module consisting of 6 fuel pins surrounding a central Molybdenum-Lithium heatpipe. The fuel pins are boron-nitride resistance heaters that are used to simulate the heat of a nuclear fission reaction. Figures 1 and 2 show an internal and external view of the PEST.

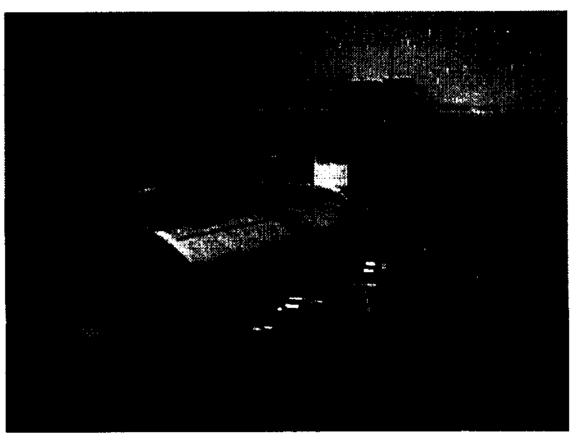

FIGURE 1. External View of The PEST.

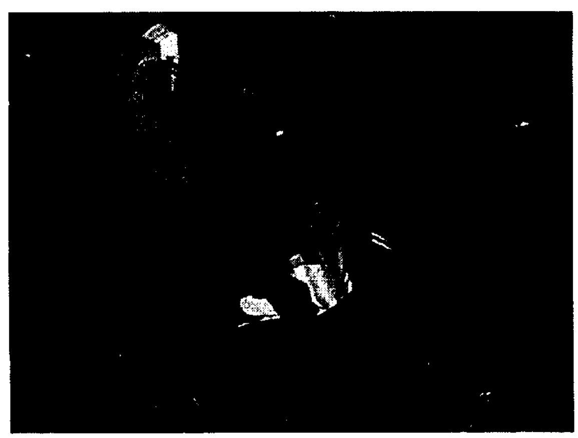

FIGURE 2. Internal View of the PEST.

PEST consists of a 24" diameter, 6 foot long, cylindrical water jacket cooled stainless steel vacuum chamber capable of operating at better than 1.0×10^{-7} Torr. The vacuum chamber is able to rotate vertically about its center axis and is mounted on a mobile support frame that facilitates quick and easy movement of the entire chamber. There are 16 2-3/4" Conflat Flange ports, 9 6" Conflat, and 1 8" Conflat ports located symmetrically about the chamber. These ports are used as viewports for visual inspection of the article or for optical data collection as well as feedthrough ports for data, gas, and power. The vacuum system is connected to the largest port. Due to the high temperature / high power nature of most simulated nuclear testing, the chamber is equipped with a water jacket to remove heat from the chamber walls produced during testing. Flow rates to both the chamber and the pumps are measured with flowmeters and monitored by a control system.

PEST was designed from the initial stages to be mobile, fully computerized, and equipped with standard off the shelf components. LabView software and National Instruments hardware was selected as the data acquisition and control (DAC) software due to its high level of industry implementation and high level of versatility. LabView is highly modular and has been customized to perform most all the routine operations standard to PEST. Additionally, each experiment is customized with its own LabView module for specific data collection or control needs. The data acquisition and control hardware consists of a SCXI chassis outfitted PCB cards specific to experiment needs. Additionally, if the DAC hardware needs to be replaced, for future experiment needs, the customized software can be retained without needing to be re-coded, greatly reducing the initial costs and time losses. All electronic controls and data acquisition devices are located on a rack that is also mobile.

The vacuum system, capable of reaching better than 1×10^{-7} Torr, consists of a water-cooled Alcatel Turbo molecular pump staged with a TriScoll 600 dry scroll vacuum pump. Pressure is monitored using multiple vacuum TC gauges for pressures above 1×10^{-3} Torr and both a Cold Cathode and Baypert-Albert ion gauge for pressures below TC gauge capability. Real-time pressure data is gathered both by a stand-alone "Varian Vacuum multi-guage controller" and LabView. The fully automatic vacuum system valves and the turbomolecular pump are controlled by LabView with coded-in procedures for vacuum chamber pump down, vacuum chamber pressurization, and fail-safe checks and routines. All valves fail closed in the event of loss of power or pneumatic pressure. Additionally, switches are located on the instrumentation and control cabinet for manual override.

31,360 Watts are currently available to PEST via 480 three phase. In the MUTT test article, this power was routed through a power feedthrough to the six heaters. The heaters were connected with 2 heaters in series to create a pair, and the 3 pairs connected in parallel to create the system. The temperature needs were met with approximately one third of the available power supplied to the heaters. The current and voltage were measured by multi-meters whose output signal is read by LabView. Power is manually controlled.

Additional PEST Capability Modifications

By the end of 1999, the ability to introduce cold gas and extraction of hot gas in the PEST should be complete.

RECOMMENDATIONS FOR FUTURE

Any future fission program whose goal is a flight system, should investigate the use of non-nuclear testing where appropriate to significantly decrease programmatic costs. The ability to test using resistance heaters to closely simulate heat from fission should be a primary design goal. Data gained from such tests may be more thorough (i.e. failure testing and margin testing) since a great deal of the safety issues associated specifically with nuclear testing will not have to be addressed.