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NASA's Evolutionary Xenon Thruster (NEXT) Component Verification Testing

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Abstract

Component testing is a critical facet of the comprehensive thruster life validation strategy devised by the NASA's Evolutionary Xenon Thruster (NEXT) program. Component testing to-date has consisted of long-duration high voltage propellant isolator and high-cycle heater life validation testing. The high voltage propellant isolator, a heritage design, will be operated under different environmental condition in the NEXT ion thruster requiring verification testing. The life test of two NEXT isolators was initiated with comparable voltage and pressure conditions with a higher temperature than measured for the NEXT prototype-model thruster. To date the NEXT isolators have accumulated 18,300 h of operation. Measurements indicate a negligible increase in leakage current over the testing duration to date. NEXT ½ in. heaters, whose manufacturing and control processes have heritage, were selected for verification testing based upon the change in physical dimensions resulting in a higher operating voltage as well as potential differences in thermal environment. The heater fabrication processes, developed for the International Space Station (ISS) plasma contactor hollow cathode assembly, were utilized with modification of heater dimensions to accommodate a larger cathode. Cyclic testing of five ½ in. diameter heaters was initiated to validate these modified fabrication processes while retaining high reliability heaters. To date two of the heaters have been cycled to 10,000 cycles and suspended to preserve hardware. Three of the heaters have been cycled to failure giving a B_{10} life of 12,615 cycles, approximately 6,000 more cycles than the established qualification B_{10} life of the ISS plasma contactor heaters.

Nomenclature

B_1	statistical number of cycles in which 1 percent of components are expected to fail with 90 percent confidence
B_{10}	statistical number of cycles in which 10 percent of components are expected to fail with 90 percent confidence
BOL	beginning-of-life
DAC	data acquisition and control system
DCIU	digital control interface unit
DS1	Deep Space 1
EM	engineering model
$F(t)$	fraction of units failing
GRC	NASA Glenn Research Center
HiPEP	High Power Electric Propulsion

HVPI	high voltage propellant isolator
IPS	ion propulsion system
ISS	International Space Station
LDT	Long-Duration Test
NEXT	NASA's Evolutionary Xenon Thruster
NSTAR	NASA Solar Electric Propulsion Technology Applications Readiness
PM	Prototype Model
PMS	propellant management system
PPU	power processing unit
SEP	Solar Electric Propulsion
SOA	state-of-the-art
t	cycles to failure
t_0	origin of distribution
VF–62	Vacuum Facility 62
Xe	xenon
β	slope or shape parameter
η	characteristic life or scale parameter

Introduction

NASA's Evolutionary Xenon Thruster (NEXT), led by the NASA Glenn Research Center (GRC), is being developed to meet NASA's future mission propulsion needs for a more-advanced, higher-power ion propulsion system (IPS) at low total development cost. The success of the NASA Solar Electric Propulsion Technology Applications Readiness (NSTAR) ion propulsion system on Deep Space 1 (DS1) secured the future for ion propulsion technology for future NASA missions (Refs 1 to 3). In-space propulsion technology analyses conducted at NASA identified the need for a higher-power, higher total throughput capability ion propulsion system beyond the 2.3 kW NSTAR ion thruster targeted for robotic exploration of the outer planets. The NEXT project is tasked with development of the next-generation ion propulsion system to meet NASA's present and future propulsion needs. The NEXT Solar Electric Propulsion (SEP) system design enhances and enables Discovery, New Frontiers, and other exploration mission classes (Refs 4 and 5). Several of the Discovery-class mission studies demonstrated NEXT outperforming the state-of-the-art (SOA) NSTAR, yielding higher net payload mass with fewer thrusters (Ref. 6). Several of the New Frontiers and Flagship-class mission studies showed that NEXT was either mission-enhancing or mission-enabling (Refs. 4 and 7). NEXT technology is applicable to a wide range of NASA solar system exploration missions, as well as earth-space commercial and other missions of national interest. NEXT affords larger delivered payloads and smaller launch vehicle size than chemical propulsion for Discovery, New Frontiers, Mars Exploration, and Flagship outer-planet exploration missions.

The NEXT system consists of a high-performance, 7 kW ion thruster; a high-efficiency, modular, 7 kW power processing unit (PPU)* with an efficiency and a specific power greater the NSTAR PPU; a highly-flexible, advanced Xe propellant management system (PMS)† that utilizes proportional valves and thermal throttles to reduce mass and volume; a lightweight engine gimbal;‡ and key elements of a digital control interface unit (DCIU)† including software algorithms (Refs. 8 to 14). The NEXT thruster and component technologies demonstrate a significant advancement in technology beyond SOA NSTAR thruster systems. NEXT performance exceeds single or multiple NSTAR thrusters over most of the thruster input power range. The wet propulsion system mass has been reduced by higher-efficiency,

*Power Processing Unit development led by L3 Comm ETI, Torrance, California.
†Propellant Management System and DCIU simulator development led by Aerojet, Redmond, Washington.
‡Gimbal development led by the Jet Propulsion Laboratory and Swales Aerospace.

higher-specific impulse, and lower specific mass. With a predicted throughput capability more than double that of NSTAR, fewer NEXT thrusters are required compared NSTAR.

Validation of the NEXT thruster service life capability is being addressed via a comprehensive service life validation scheme utilizing a combination of test and analyses. A NEXT service life assessment was conducted at GRC employing several models to evaluate all known failure modes incorporating the results of the NEXT 2,000 h wear test conducted on an engineering model (EM) NEXT ion thruster at 6.9 kW input power. The assessment predicts the earliest failure occurring sometime after 750 kg of Xe throughput, well beyond the mission-derived propellant throughput requirement of 300 kg (Ref. 15). To verify the NEXT thruster service life model and qualify the NEXT thruster, the NEXT Long-Duration Test (LDT) was initiated. To date the NEXT LDT has demonstrated 17,000 h of operation processing 348 kg of Xe and demonstrating 13.0×10^6 N·s (Ref. 16). The goal of the NEXT LDT is to verify by direct test that the thruster service life capability predicted is accurate and achievable. This verification by test is a costly, yet indisputable method of thruster service life validation.

Complementary sets of NEXT component verification activities are ongoing or are planned to augment the NEXT LDT in support of validating the NEXT thruster service life assessment. A life test of two high voltage propellant isolators (HVPIs) is ongoing. The HVPIs provide electrical isolation for the Xe feed system from the discharge anode and cathode, which operate at high voltages. In the NEXT ion propulsion system, these potentials can reach as high as 1800 V from ground. The HVPIs were selected for validation even though they are based upon a heritage design because they sustained enough design changes and operate in a slightly different environment (Refs. 17 to 19). Factors leading to the decision of component validation include: NEXT HVPI design changed to accommodate higher operating voltages, NEXT HVPI hardware procured from a different vendor, and to verify NEXT HVPIs can handle NEXT operating pressures and temperature requirements. Two prototype-model propellant isolators, nearly identical to the design of the NEXT LDT HVPIs but fabricated from a different vender, are under-going a life test under simulated environmental conditions of voltage, pressure, and temperature. The temperature for the HVPI testing was initially set at the anticipated temperature for the NEXT Prototype-Model (PM) thruster operating in the harshest environment. Subsequent testing of the NEXT PM thruster revealed better thermal management than accounted for leading to reduced operating temperatures. The HVPI testing was continued at the elevated temperature. The primary objectives of the HVPI testing are to ensure that the design has sufficient voltage and thermal margin, identify unexpected life-limiting phenomena, characterize the HVPI performance over time, and qualify the NEXT HVPI for full power operation of a NEXT ion engine for its life requirement. The test will continue for 28,000 h or until the leakage current on the propellant isolators exceeds 100 μA. The upper bound on acceptable leakage current is extremely conservative and was chosen to be the same as the requirement for the NSTAR HVPIs (Ref. 18).

Cathode heaters, developed for the International Space Station (ISS) plasma contactor, are used to raise the low-work-function emitter temperature inside the hollow cathodes to the level at which thermionic emission occurs during the cathode ignition process. The NEXT neutralizer and discharge chamber hollow cathodes use sheathed helical heaters coiled on cathode tubes of ¼ and ½ in. diameters, respectively. The NEXT neutralizer ¼ in. heaters are identical in materials, fabrication techniques, and dimensions to the ISS heaters permitting verification by similarity (Ref. 20). The ½ in. heaters are different in dimensions and operating voltages requiring validation though the material and fabrication techniques have heritage from the ISS plasma contactor. Half inch GRC-manufactured heaters have completed cyclic life testing to evaluate reliability and validate the heater manufacturing and performance. Five ½ in. heaters have completed cyclic testing with two units suspended after 10,000 cycles to preserve hardware, while three units were cycled to failure. An encompassing GRC-manufactured heater qualification program has begun with these cyclic heater tests offering manufacturing verification.

This paper documents the test setups and results obtained to date for the HVPI and ½ in. heater tests. Additional component testing such as thin-film adhesion to discharge chamber wire mesh and cathode ignition testing are underway or are planned.

HVPI Testing

The NEXT HVPI design concept is based on the NSTAR HVPI that was successfully tested at the component and thruster level for 16,000 and 30,000 h, respectively (Refs. 18 and 21). The NEXT HVPIs provide electrical isolation of the gas feed system at ground potential from the ion engine hollow cathode and discharge chamber, which can be at a potential of 1800 V above ground. Additional information on the HVPI initial tests can be found in Reference 22. The life validation test of two HVPIs was started on January 5, 2006. The results of the HVPI testing to date are included in the following section.

High-Voltage Propellant Isolators

The NEXT HVPIs provide electrical isolation for the Xe feed system, at ground potential, from the ion engine hollow cathode and discharge chamber, which can be at a potential of 1800 V above ground. The NEXT isolators based on the NSTAR design, are made of nickel-alloy housing flanges, an alumina housing, and backup alumina rings (Ref. 13). The braze is oxygen free, high conductivity copper. The HVPI has shields to prevent line-of-sight deposition of sputtered efflux or external contaminants. Shields are used because surface coatings on the HVPI alumina housing can cause unwanted current leakage from high voltage to ground. A photograph of the HVPIs is shown in Figure 1. In addition to having a much higher voltage capability compared to the NSTAR HVPI, the NEXT HVPI design has a smaller radial envelope than the NSTAR unit. The smaller diameter reduces mass and mitigates risk associated with vibration environments.

HVPI Test Setup

The HVPI test is being performed in GRC's Vacuum Facility 62 (VF–62), which is a cryogenically pumped vacuum chamber 30 cm in diameter and 76 cm long. An oil-free roughing pump is used in conjunction with a cryogenic pump, which has a pumping speed of 2100 l/s. The typical operating pressure is 0.1 mPa. The pressure in the vacuum chamber is very low because the Xe flow through the HVPIs does not exhaust into the chamber but is plumbed through the chamber flange to an auxiliary scroll pump that maintains a pressure of about 38 Pa at the HVPI exit. Two isolators are heated inside a radiation shield by four tungsten-halogen lamps. A laboratory power supply provides high voltage across the isolators while leakage currents are measured by an electrometer with capability to measure less than a nanoampere (Ref. 2). More detailed information on the test setup can be found in Reference 22.

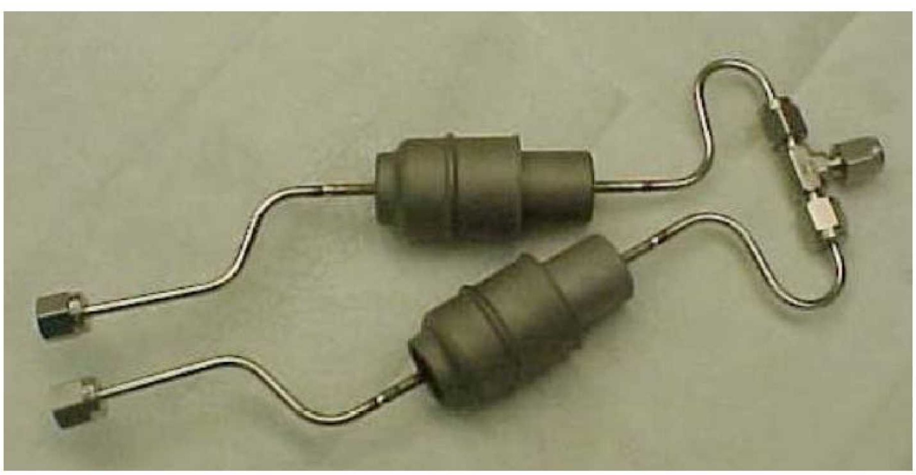


Figure 1.—NEXT HVPIs with propellant tubing prior to installation.

Operating Parameters and Procedure

It was decided that the HVPI component test be conducted similar voltage, temperature and pressure conditions as it will experience with a thruster. A voltage of 2300 V was selected to have at least 500 V over the maximum voltage set point. A temperature of 260 °C was selected because that is estimated to be about 40˚C higher than isolator temperatures for the NEXT EM thruster operated at full power, without an adiabatic enclosure and without solar simulation. Preliminary thermal model results predict that the anode of the NEXT Prototype Model (PM) thruster discharge chamber will have a temperature about 75 °C cooler than the EM thruster when operated at full-power (Ref. 23). Given these temperature indications, it is estimated that the HVPI component test temperature of 260 °C would provide about 65 °C margin for the PM thruster in the worst-case environment that included three operating thrusters in an adiabatic enclosure, at 0.85 AU, and 38° off-axis sun angle (Ref. 23). Finally, a pressure of approximately 2.7 kPa downstream of the isolators is being used (Ref. 22). The life validation test will be conducted for a period of no less than 28,000 h, which is the qualification-test requirement for the NEXT thruster (Refs. 15 and 24). Additional information on the definition of the HVPI testing parameters, pretest preparations, and functional tests can be found in Reference 22.

HVPI Results

During the life validation test, the temperature of the HVPIs is maintained at 260±5 °C, voltage is set to 2300 V, and the downstream pressure is maintained at 2.7±0.3 kPa. Testing is initiated only if the facility pressure is below 270 µPa. As of June 2008, more than 18,300 h of operation have been accumulated. Test down time has been minimal resulting in a test duty cycle of about 87 percent. The background pressure in the test facility during the test was typically 130 µPa. Figure 2 shows the leakage current through both isolators versus time. At the beginning of the test the leakage current was less than 0.1 nA and very slowly increased with time. Between 7500 and 9500 h, the current measurements became erratic. This was due to a short circuit from one of the radiant heater electrical sockets to the vacuum facility that caused ground currents that coupled into the isolator circuit affecting the leakage current measurement. The heater socket was replaced and the test resumed. Leakage current measurements returned to the levels they were before the incident and seem to continue its previous trend. The leakage current is currently increasing at a rate of approximately 0.1 nA every 2900 h. Its value is five orders of magnitude lower than the maximum allowable leakage current requirement of 100 µA, and there is no threat to long-term operation.

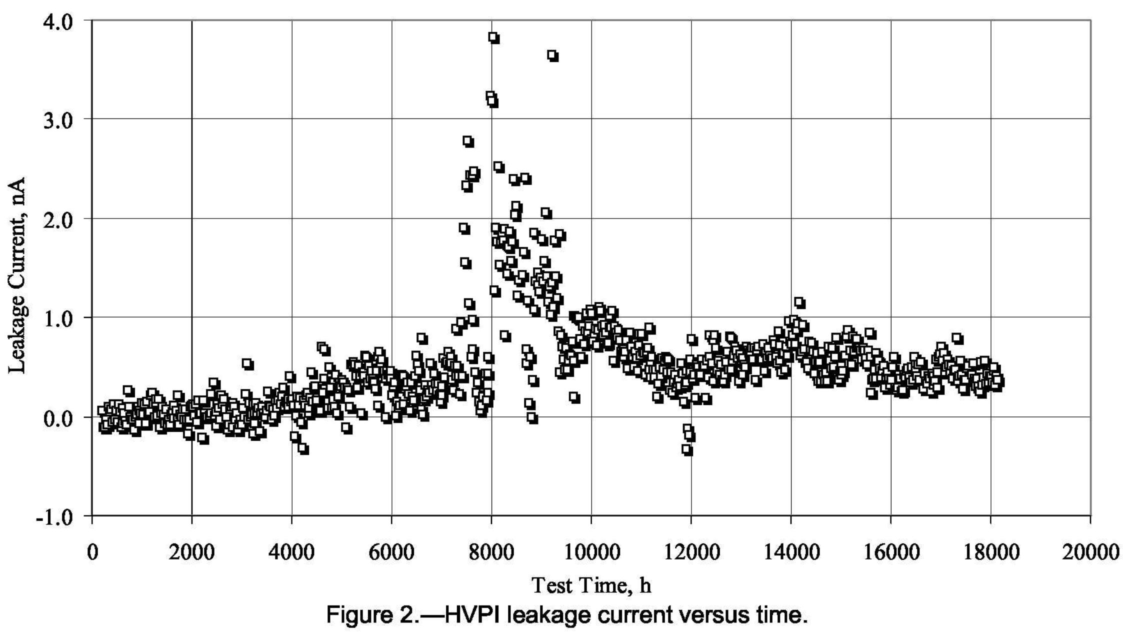


Figure 2.—HVPI leakage current versus time.

Half-Inch Heater Cyclic Testing

The following section describes the heaters that have been tested, the test setup, the testing operating parameters and procedures, and the cyclic testing results. A comprehensive GRC-manufactured ½ in. heater qualification program has been initiated. The cyclic heater tests results presented in this paper offer manufacturing process validation and demonstrate confidence that the ½ in. heater design will yield the required cycle lifetimes. The target cycle lifetime is greater than the ISS B_{10} lifetime of 6,679 cycles.

Half-Inch Heater Test Articles

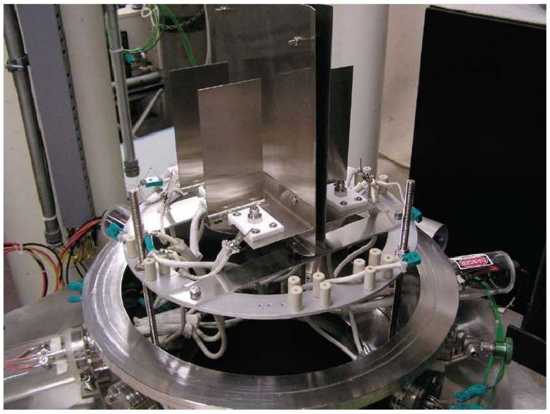
Five different ½ in. heaters were subjected to cyclic testing. Photographs of the test articles and summary information are given in Table 1. Four of the heaters tested were installed in complete discharge cathode assemblies (DCAs) including the electron emitting inserts to match the thermal mass and environment. A ½ in. heater coil section, previously used and removed following the NEXT 2,000 h wear test, was installed on a hollow cathode tube with radiation shielding, but no emitter (Refs. 25 and 26). This ½ in. heater coil, as well as one of the DCA's, was outfitted with a thermocouple located on the cathode tube in the plane of the inside edge of the cathode orifice plate. The ½ in. heater coil had previously operated for 40 ignitions and 8 cathode conditioning sequences during the NEXT 2,000 h wear test totaling 37.4 h of current application (196 A·h) (Ref. 25). Another heater that had been operated for significant duration is EM DCA2, which has a graphite keeper electrode and was operated during the High Power Electric Propulsion (HiPEP) 2,000 h wear test (Ref. 27).

TABLE 1.—HALF-INCH GRC-MANUFACTURED HEATER CYCLIC TEST RESULTS SUMMARY

Article	Photo	Cycles Demonstrated	Status	Notes
½ in. HTR–10		13,895	Failed open-circuit	Coil section from NEXT 2 kh wear test mounted on new cathode tube; No insert
EM DCA1		14,257	Failed open-circuit	Completed EM DCA
EM DCA2		13,789	Failed open-circuit	EM DCA used in HiPEP 2 kh wear test; Graphite keeper (Ref. 27)
EM DCA10		10,000	Operational: suspended from test	Completed EM DCA
EM DCA11		10,003	Operational: suspended from test	Completed EM DCA

Cyclic Heater Test Setup

The DCAs and cathode tube were mounted on the heater test fixture, shown in Figure 3, which allows simultaneous testing of up to 6 heaters. Ceramic insulators at the mounting location (bottom) provide electrical and thermal isolation against conducted heat. Stainless steel radiation shields eliminate radiated heat interaction between neighboring heaters during testing. The test fixture is installed in VF–65 at GRC. This is a 91 cm long by 48 cm diameter cryogenically pumped belljar with a glass dome. The average, and typical, operating pressure of the bell jar during current application is 13.3 μPa. The heater test is controlled by an automated data acquisition and control system (DAC) that



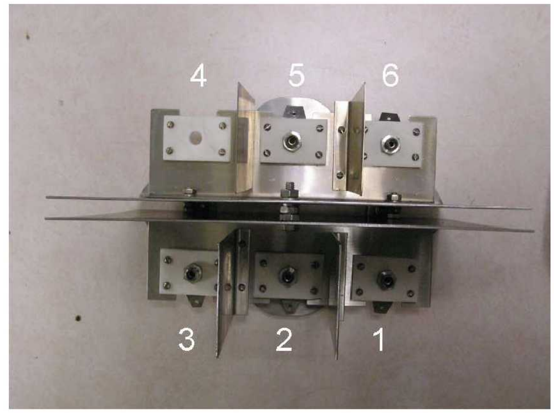


Figure 3.—Half inch heater test fixture installed in VF65 with bell jar removed (left) and top view (right).

utilizes isolated Hall effect sensors to measure currents. Voltages are measured at the vacuum feed through to reduce voltage drops. Heater temperatures for the two units are made with R-type thermocouples. Additional information on the heater test setup can be found in Reference 22.

Operating Parameters and Procedure

The test sequence includes two procedures. First, the heaters complete a conditioning procedure established during the ISS plasma contactor effort that has been used in for both NSTAR and NEXT programs to remove absorbed impurities on the hollow cathode emitter surfaces. This procedure is only used when the bell jar is exposed to elevated pressures, such as venting of the facility, and prior to cyclic heater testing. The heater cyclic testing consists of repeated cycles (on for 6 min and off for 4 min) operating at a fixed current of 8.50 A, which is the current used for cathode ignition. The 6 min duration is consistent with the ISS plasma contactor heater cyclic testing to establish the B_{10} life for ¼ in. GRC-manufactured heaters. The 6 min duration is also consistent with the NEXT EM hollow cathode ignition database for encompassing >90 percent of all discharge cathode ignition times to date. The 4 min off duration is consistent with ISS plasma contactor heater qualification testing. Cycles are continuously carried out with the exception of facility issues, test setup modification, and data recording breaks, which occur approximately every 1,000 cycles. The heaters, cycled until failure or suspension, are shown with 8.50 A heater current in Figure 4. The most common failure mode is an open circuit of the center conductor due to grain growth. The cyclic life test is a worst-case test subjecting the NEXT ½ in. heaters to orders of magnitude more cycles than required for deep space missions. The success criterion for the ½ in. heater cyclic life test is heaters meet or exceed the B_{10} lifetime of the ISS plasma contactor hollow cathode assembly. This is the statistical number of cycles at which 10 percent of the heaters would be expected to have failed with 90 percent confidence. The ISS B_{10} life was established to be 6,679 cycles.

Cyclic Heater Test Results

Since the testing cycles are operated at set currents, the independent parameter of interest is heater voltage. Equivalently this voltage can be converted to an operating heater resistance by dividing the voltage by 8.50 A. Observations about the voltage as a function of time during heater "on" segments as well as the end of heater "on" voltage as a function of heater cycle can give important information about the heater operations. The same is true of heater hot resistance. Note that because of its shorter length the ½ in. heater coil section demonstrates a reduced voltage compared to the heaters inside EM DCAs. During testing additional heater section was added in series with the ½ in. heater coil resulting in an increase in operating voltage that turns out to be comparable to the other heaters operating in DCAs. As a matter of preference, individual heater segments will be plotted as voltage versus time, while heater end-of-current performance will be plotted as a resistance normalized to beginning-of-life (BOL) value versus

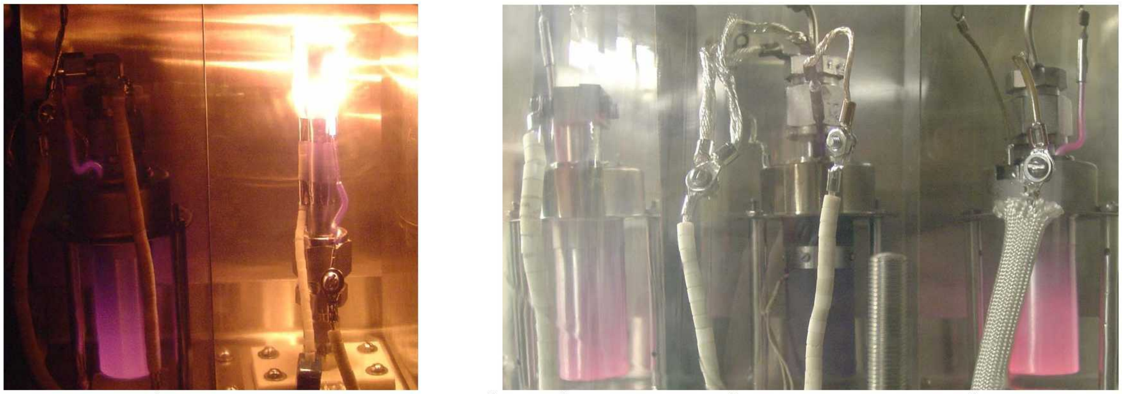


Figure 4.—Half inch heater cyclic test images from left to right: EM DCA 11, HTR-10, EM DCA 10, EM DCA2, EM DCA 1.

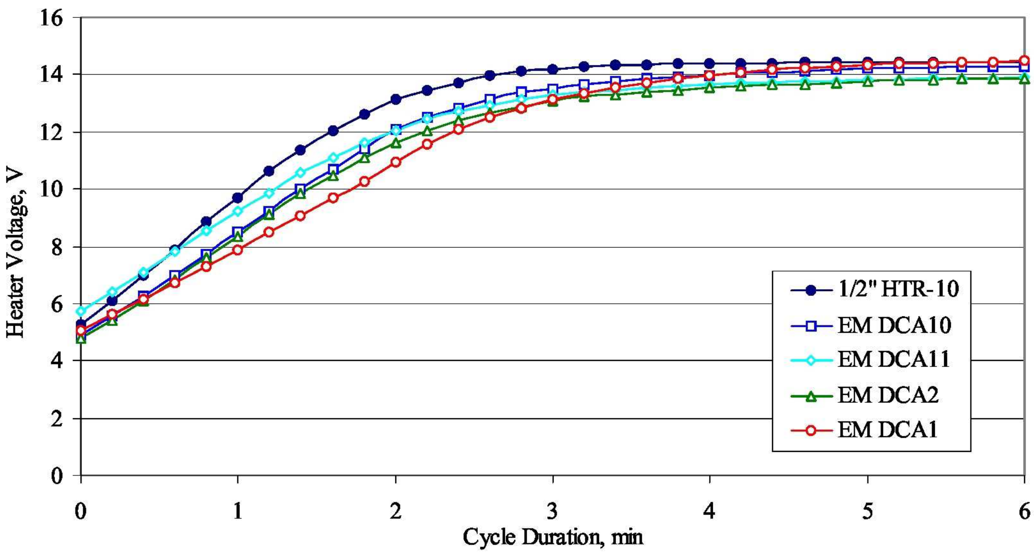


Figure 5.—Typical heater voltage versus time during 6 min "On" cycle.

cycle number. This format allows easy interpretation of typical ½ in. heater operation during cycles and facilitates comparison of various heater performances over the test duration. A typical voltage versus time characteristic is shown for the five heaters in Figure 5. The data show comparable characteristics consistent with the rise in voltage expected from a resistive filament whose temperature is increasing with time. All heater voltages asymptote to approximately 14 V. None of them demonstrate a voltage overshoot that can be associated with thermal-mechanical effects or leakage current path production.

The cyclic heater voltage (or equivalently resistance) values, normalized to the BOL values, are shown as a function of cycle number in Figure 6. Two ¼ in. ISS plasma contactor heaters are shown for reference. ISS HTR-038 was one of the three heaters cycled to failure during the plasma contactor qualification program that established the ISS heater B_{10} life. The ½ in. heater normalized voltage at the end of the 6 min "on" cycle all exhibit increasing trends with time as expected. Typical increases observed over the ISS plasma contactor heater life are 5 to 10 percent higher than BOL values. Three of the NEXT heaters exhibit similar magnitude increases as the ISS plasma contactor heaters. Two of the ½ in. heaters reveal increasing end-of-cycle voltage values that are 17 to 18 percent higher than beginning-of-test. Two of the ½ in. heaters, EM DCA10 and EM DCA11, were operated for ~10,000 cycles and then suspended to preserve operation of the DCAs. The other three heaters were cycled to failure and all failed open-circuit. The open-circuit failures were confirmed by post-test resistance measurements. The presumed failure locations are at the center coil location due to center conductor grain growth.

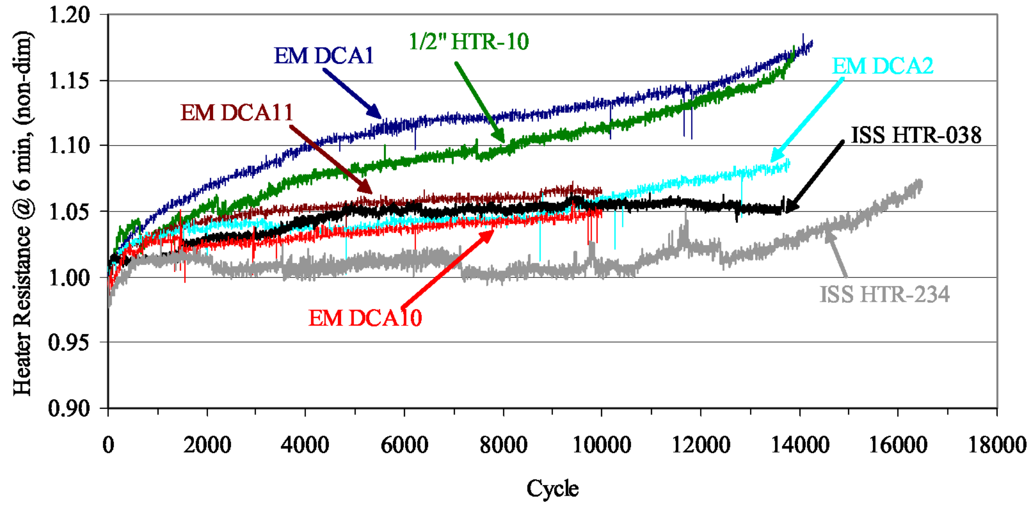


Figure 6.—Heater "hot" resistance normalized to BOL values versus time.

Destructive post-test analyses are beyond the scope of this paper. The numbers of individual heater cycles to failure are listed in Table 1. Prior to heater failure, a voltage-runoff characteristic is typically observed where the end-of-cycle voltage begins to increase with cycle number at a greater rate than over the majority of the cyclic test. Note that neither of the suspended heaters, EM DCA10 or EM DCA11, exhibited this type of behavior prior to suspension of the cyclic test.

A Weibull analysis of the three failed ½ in. heaters was performed using a rank regression to determine the values for the two-parameter Weibull distribution. The Weibull distribution is defined in Equation (1). The values for β and η are determined to be 51.19 and 14,105 with a correlation coefficient of 0.93, respectively. The determined Weibull distribution is plotted with the three failed ½ in. heaters in Figure 7. The Weibull distribution is used to calculate the ½ in. GRC-manufactured heaters survival probability, with 90 percent confidence, shown in Figure 8. *Included in the ½ in. heater survivability plot are the* B_1 *and* B_{10} *cycle lifetimes of 11,457 and 12,615 cycles, respectively. These values exceed the target requirement and are considerably larger than the corresponding ISS plasma contactor values of 3,921 and 6,679, respectively.* Two factors contribute to the calculated increase in statistical life: all ½ in. heaters lasted ~2,000 cycles more than the longest life ISS heater and the ½ in. heater failures all failed within 500 cycles of each other compared to the ISS spread of ~2,000 cycles. The combination of these two factors cause the significant increase in GRC-manufactured ½ in. heater statistical life. It should be noted that the ¼ in. ISS heaters, including HTR-038, were cycled in a power-limited manner compared to the ½ in. heaters that were cycled in a current-limited fashion. The latter would be the harsher test as heater voltage, and therefore heater power, would continually increase over the testing duration.

$$F(t) = 1 - e^{-\left(\frac{t - t_0}{\eta}\right)^{\beta}} \tag{1}$$

A cause for the extended ½ in. heater cyclic life may be due to a decreased operating temperature compared to the ¼ in. heaters. Thermocouple data from the ½ in. HTR-10 and ¼ in. HTR-234 articles at end of the "on" cycle are shown as a function cycle number in Figure 9. In both cases the heaters were friction fit to cathode tubes with radiation shielding spot-welded on the outside of the heater coils, i.e., same setup as ISS heater qualification testing. No inserts were installed in the cathode tubes nor were keeper electrodes installed. The temperature data indicate the ½ in. heater operates ~200 °C cooler than the ¼ in. heater. Since grain growth leading to center conductor fracture is the expected failure mode and time at temperature is the dominant parameter for this behavior, it is expected that a heater that operates at a reduced temperature would last longer.

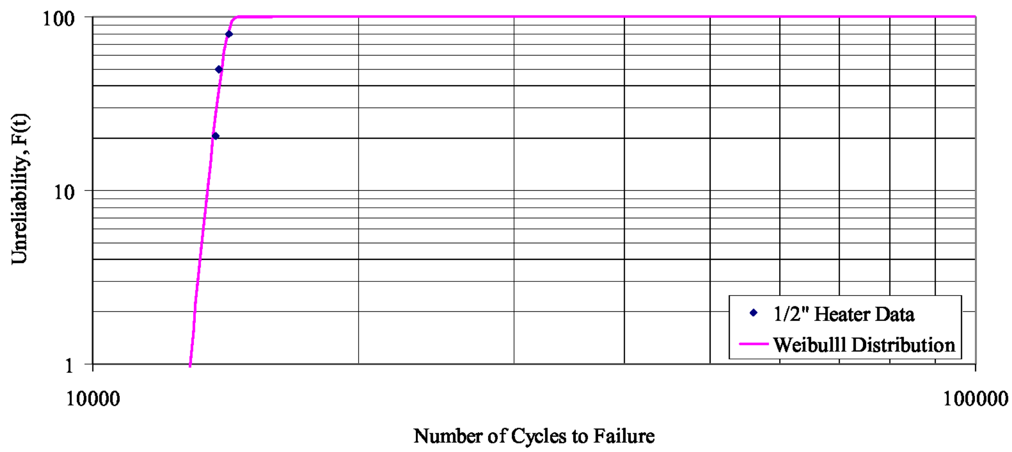


Figure 7.—Half inch GRC-manufactured heater Weibull probability plot.

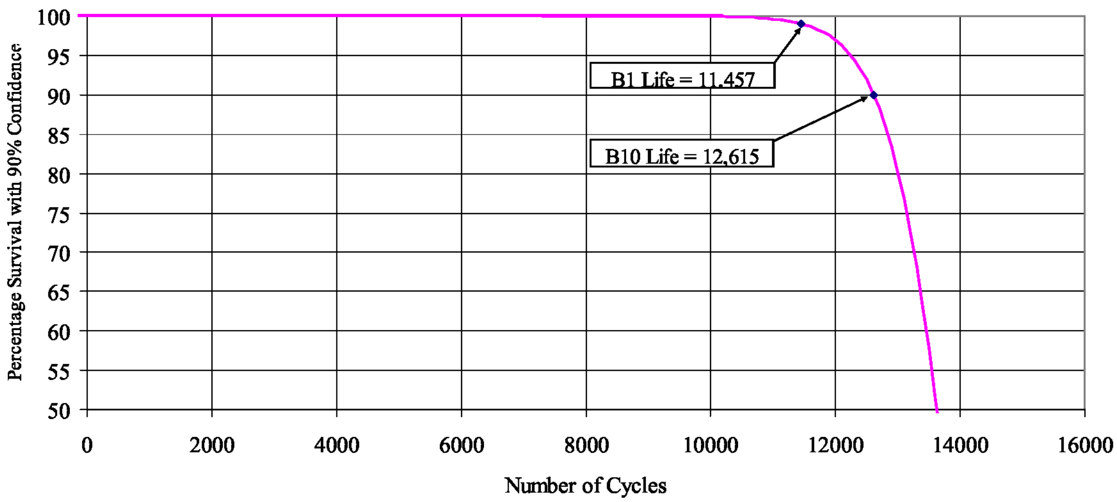


Figure 8.—Half inch GRC-manufactured heater Weibull analysis results.

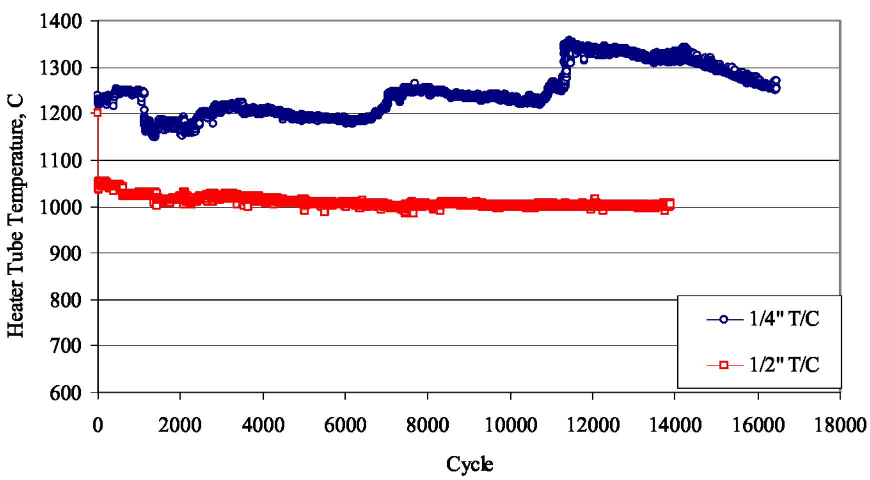


Figure 9.—Half inch heater coil, HTR-10, and ¼ in. heater coil, HTR-234 cathode tube temperatures in the plane of the orifice plate upstream surface. No inserts in cathode tubes or keepers, but radiation shield installed.

Conclusion

A critical part of the NEXT thruster validation and qualification program is component lifetime testing. In addition to the thruster life test underway, several component life tests are completed, underway, or planned. The status of the high-voltage propellant isolator testing is presented. To date the propellant isolators have demonstrated 18,300 h of operation at an elevated temperature 65 °C higher than the worst case expected flight temperature and representative pressure. The leakage current across the isolators has increased insignificantly and is currently five orders of magnitude lower than the maximum requirement. There is no threat to long-term high-voltage propellant isolator operation. The ½ in. heater cyclic testing results of five GRC-manufactured test articles are presented. A comprehensive GRC-manufactured ½ in. heater qualification program has begun with the initial cyclic tests instilling confidence in the heater design and verification of manufacturing processes. Two heaters were cycled to 10,000 h and these two tests were suspended to preserve hardware. Neither demonstrated the voltage runoff observed prior to heater failure. Three of the heaters were cycled to failure with a minimum life of 13,789 cycles prior to failure. A Weibull analysis was performed on the three failed heaters, all of which failed open-circuit. The GRC-manufactured ½ in. heaters have a B_{10} lifetime, 12,615 cycles, which is considerably greater than the ¼ in. GRC-manufactured heaters, 6,679 cycles (the target requirement). The greater cyclic life may be in part due to lower operating temperature for the ½ in. heater inside the DCA. The increase in the ½ in. heaters end-of-cycle "hot" resistances with number of cycles is consistent with ISS plasma contactor behavior.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Component testing is a critical facet of the comprehensive thruster life validation strategy devised by the NASA's Evolutionary Xenon Thruster (NEXT) program. Component testing to-date has consisted of long-duration high voltage propellant isolator and high-cycle heater life validation testing. The high voltage propellant isolator, a heritage design, will be operated under different environmental condition in the NEXT ion thruster requiring verification testing. The life test of two NEXT isolators was initiated with comparable voltage and pressure conditions with a higher temperature than measured for the NEXT prototype-model thruster. To date the NEXT isolators have accumulated 18,300 h of operation. Measurements indicate a negligible increase in leakage current over the testing duration to date. NEXT ½ in. heaters, whose manufacturing and control processes have heritage, were selected for verification testing based upon the change in physical dimensions resulting in a higher operating voltage as well as potential differences in thermal environment. The heater fabrication processes, developed for the International Space Station (ISS) plasma contactor hollow cathode assembly, were utilized with modification of heater dimensions to accommodate a larger cathode. Cyclic testing of five ½ in. diameter heaters was initiated to validate these modified fabrication processes while retaining high reliability heaters. To date two of the heaters have been cycled to 10,000 cycles and suspended to preserve hardware. Three of the heaters have been cycled to failure giving a B10 life of 12,615 cycles, approximately 6,000 more cycles than the established qualification B10 life of the ISS plasma contactor heaters.

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