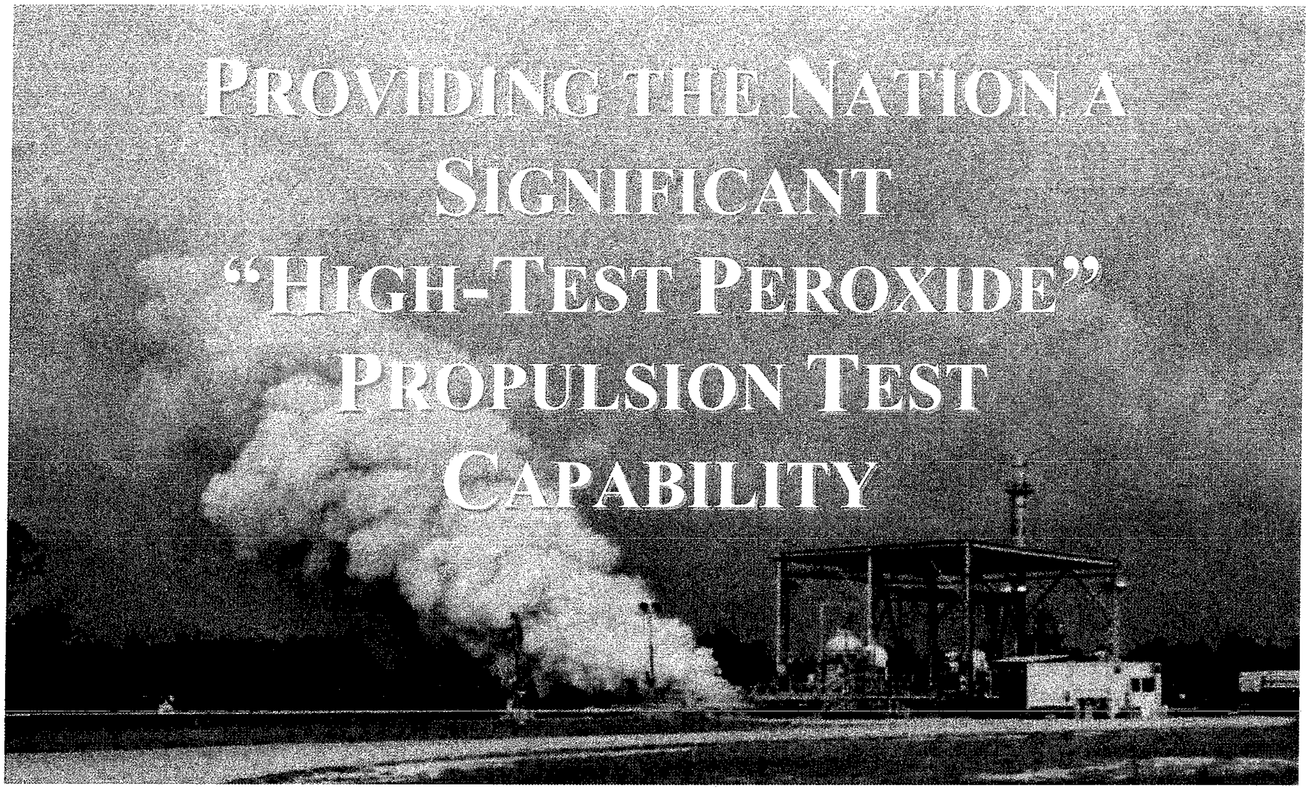

R. Bruce
NASA SSC Project Manager

G. Taylor, D. Beckmeyer, S. Warren, S. Dracon, B. Powell, D. Goodwin
NASA SSC Test Operations

P. Rieder
NASA SSC Test Engineering

NASA John C. Stennis Space Center, MS 39529

R. Nichols
Lockheed Martin Space Operations - Stennis Programs,
Stennis Space Center, MS 39529

Abstract

Renewed interest in high-test peroxide, as a propellant, required the development of a facility capable of testing rocket propulsion systems. The development of this capability at the NASA Stennis Space Center (SSC), MS, focused on meeting this requirement. The challenges, accomplishments, and lessons learned associated with developing the SSC E3 Test Facility's high-test peroxide capability are presented herein.

Introduction

The E3 Test Facility at NASA's John C. Stennis Space Center, MS, provides a high-test peroxide capability for conducting component development testing of combustion devices, rocket engine components, and small/subscale complete rocket engines and boosters. The resurgence of interest in hydrogen peroxide as a propellant and the requirement for a larger-scale ground test capability to meet the needs of research and development efforts prompted the development of this facility's capabilities.

The E3 test facility consists of 2 test cells with Cell 1 primarily used for horizontal firings of LOX and GOX hybrid motors, and Cell 2 dedicated to testing of hydrogen peroxide and/or hydrocarbon fueled test articles. The facility is currently testing with H_2O_2 concentrations of 85%, 89%, and 98%. The hydrocarbon fuel used to date is JP-8, but additional hydrocarbon fuels are being evaluated based on customer requests, safety, environmental issues, and facility capability and compatibilities.

The facility has capability to deliver propellants at pressures up to approximately 1200 psig. The Cell 2 location can support both vertical and limited, horizontal firing test positions. The firing positions for Cell 2 are located over a flame bucket, which additionally serves as containment for any inadvertent peroxide or hydrocarbon fuel discharges. An available single-axis 10,000 lbf thrust measurement system (TMS) can be installed in the vertical position. An upgraded horizontal firing capability, which will also utilize the TMS, is in development.

The E3, Cell 2 test stand was brought on-line in November 1998, and has been used in support of programs primarily using 85% to 89% H_2O_2 and JP-8 propellants. Component level testing of a catalyst bed using 98% H_2O_2 is scheduled for late calendar year 1999. Testing durations have varied from a few seconds to a current long duration test firing of 140 seconds. Plans are in work for an upcoming 200-second duration test firing. These durations are based on commodity consumption versus maximum run tank volumes, combined with predicted facility heating rates and effects.

This paper will also provide a brief overview of programs utilizing this facility as well as describe some of the handling and safety issues encountered in development of the facility. The facility and its capabilities are further described in the attached Addendum I. Figure 1 illustrates a nominal test configuration for Cell 2.

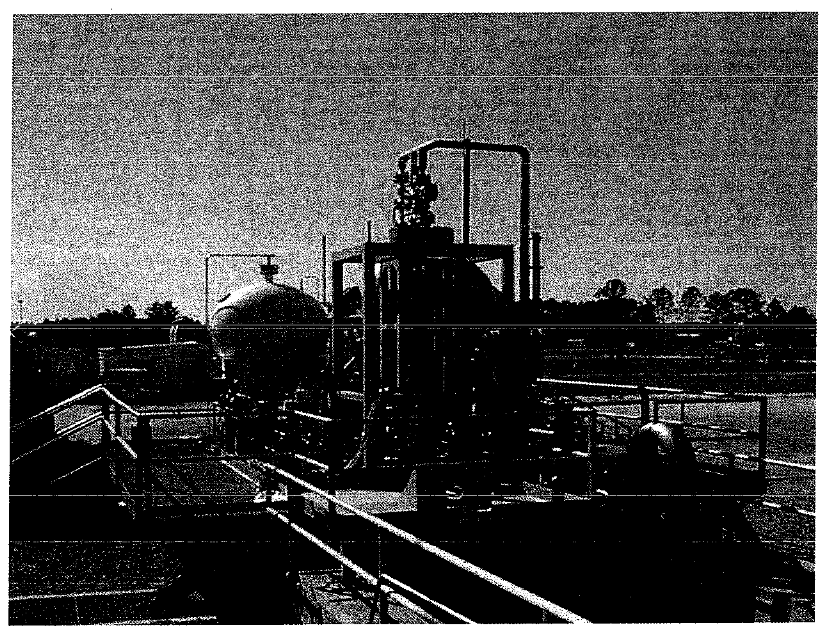

Figure 1. E3 Cell 2 High-Test Peroxide Test Stand
(Test Article & TMS Installed at Vertical Position)

Facility Development Considerations

The development of a new facility capability using commodities for which there was no in-house expertise presented several new challenges to the SSC E3 Team. High-test peroxide is certainly not a new commodity to this industry, but it is a commodity, which had not been in use at SSC. Therefore, the design and development of a new test facility capable of testing rocket engines in the 10,000 lbf thrust class was approached cautiously. As a result, the initial expertise identified was from the peroxide manufacturers and limited users. Several peroxide manufacturers were consulted to review designs, advise on component selection, and provide inputs to operational scenarios. This assistance was invaluable. However through the process of developing, activating, and bringing the facility on-line operationally, several lessons were learned with respect to differences relative to production and long-term storage and exposure versus short-term operations for individual testing periods. These lessons learned are incorporated in a following section. The primary considerations dealt with in developing this facility were: 1) handling & operating philosophies, 2) tankage, 3) component selection/compatibility, and 4) cleanliness. These are described in further detail below.

Handling/Operating Philosophy

The philosophy for handling and operating with high-test peroxide was the first primary consideration to be resolved. Manufacturers were consulted for handling guidelines with respect to safety, personnel protective equipment, and processes. Additionally, the SSC in-house environmental and safety personnel were involved to insure environmental compliance and personnel or facilities were not exposed to undue risk.

The overall philosophy employed was to utilize industry standards and recommendations as much as possible with modifications as required for SSC unique applications. This philosophy carried over to the safety and environmental issues and approaches. The top priorities were to maintain safety of facilities and personnel coupled with being as environmentally responsive as possible.

The handling/safety concerns were addressed based on the following approaches:

- All personnel associated with E3 and surrounding complexes were provided initial safety training for peroxide. Test team personnel were also required to attend additional test and handling specific training.

- Personal Protective Equipment (PPE) purchased for all personnel working with peroxide operations. Personnel trained with the PPE and required to don equipment whenever working with or around peroxide exposures.

- Implement an OSHA Process Safety Management (PSM) Program. The quantity of peroxide involved with receipt of an ISO container (~40,000 lbs) required the PSM program.

- Facility remotely operated for all initiations of test sequences/operations.

- The ISO container to be setup for continual around-the-clock monitoring of temperature differentials, with alarm limits established and call-in procedures setup for off-hour situations.

- All run systems exposed to peroxide to be monitored for temperature increases and un-commanded pressure changes.

- The run tanks and lines skid mounted over a flame bucket, with the skid providing initial containment until any spills could drain into the flame bucket.

The primary operational philosophies and guidelines adopted for the facility development were:

- The run system would not be utilized for storage. The quantity of peroxide transferred into the run tank and system would be limited to the nominal quantity required for conduct of the planned test activities on a daily basis. At the end of a day's testing, any residual peroxide would be discharged out the facility catalyst bed to safe the system. See Figure 7 for a view of the facility catalyst bed.

- A facility cat bed required for decomposition of any residual peroxide in the run tank and lines, under normal operating scenario, prior to its release into the flame bucket. Flame bucket contains materials, which over time could react with the peroxide and cause potential problems.

- Emergency dump of the peroxide would be into the flame bucket for containment, but normal process operations would utilize the facility catalyst bed.

- All propellant tank vents and peroxide run line relief valve discharge plumbed to the flame bucket. JP-8 run system relief valves plumbed to a JP-8 waste container.

- Flame bucket to provide containment of peroxide and fuel discharges from the test article and/or facility systems. Peroxide waste in the flame bucket must decompose below established thresholds before being pumped out. Once waste peroxide content at required level, the waste is then transported to an oil-water separator for final discharge per environmental requirements.

- Peroxide tanking/transfer operations require the storage container to be positioned near transfer pump. The transfer is made with a double diaphragm pump. Once transfer quantity is reached, the isolation valve at the storage container is closed and the diaphragm pump continues pumping until a slight vacuum is achieved, thus insuring maximum quantity of peroxide is removed from the transfer line. The peroxide tank is also isolated and the transfer lines are to be flushed out with deionized (DI) water, and then dried with gaseous nitrogen. Once the transfer lines are cleaned out, the storage container or ISO container is then returned to its bermed location. See Figure 6 for a view of transfer operations from an ISO container to the run tank.

- Deionized water to be used for all flushing and peroxide system activation and checkouts. The DI water system to be maintained to a minimum 15 meg-ohm/cm^2 quality rating.

The above philosophies and guidelines were used to insure a safe facility and test operation.

Tankage

A facility tank available for use as a peroxide run tank was constructed of 321 series stainless steel, which is a Class 2 material. The tank is a 500-gallon, single-wall, spherical tank, with nozzle penetrations top and bottom, and lower-half side penetrations for temperature or pressure measurement. The top of the tank has three nozzles, which are used for pressurization, venting, and additional emergency relief. All tank vents/reliefs routed to a common header and vented below grade of the test skid and into the flame bucket. The nominal vent/relief capacity required for a peroxide storage tank was waived due to the operating philosophy that the test tank is designated as a run tank and will not be used for storage and all peroxide shall be removed post-test on a daily basis.

The side penetrations in the lower quadrant used for temperature measurement. Two thermocouples are installed into the tank. The thermocouples are installed with thermo-wells and one thermocouple inputs to the data system. The other thermocouple is installed with a digital readout, for direct temperature readings by personnel working around the tank. The thermo-wells are used to prevent peroxide exposure when thermocouples are serviced or replaced. The thermo-wells additionally minimize the potential for leakage or cross-contamination.

The nozzle at the bottom of the run tank connects to the run line. This nozzle has a 6" Grayloc seal, which is reduced down to a 2" run line. This nozzle contains side ports, which are used for filling operations and connect to a sight glass for determining the liquid level within the tank. The determination of the liquid level is critical for the run philosophy of only tanking the required quantity of peroxide expected to be expended within that day's testing period.

The Hydrocarbon Fuel (JP-8) run tank is a 250-gallon, carbon steel vessel. The tank was cleaned to SSC's oxygen cleanliness standards to minimize any particulate matter being introduced into the system. The fuel is filtered entering the run tank and then again in the run line. All components downstream of the run line filter were initially cleaned to the SSC oxygen cleanliness standard. The fuel run tank is configured similar to the peroxide tank with nozzles on top and bottom for pressurization/venting and discharge to the run line, respectively. The fuel run line from the tank is a 1" stainless steel tube system. Figure 2 illustrates the run tanks as mounted to the test stand skid.

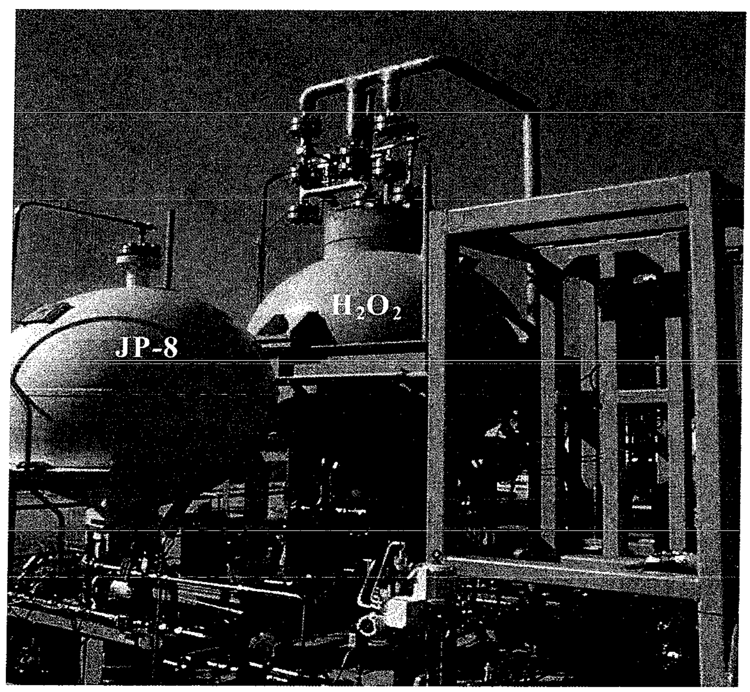

Figure 2. JP-8 Run Tank & H_2O_2 Run Tank

Component Selection/Compatibility

The component selection and compatibility issues were the most critical of all considerations. Due to the lack of experience with high-test peroxide, an extensive data search was initiated to obtain current information relative to today's materials and availability coupled with data available from previous usage during the 1950's and 1960's. The selection of the types of components was easily done based on experience with test facility systems and operations, but the actual materials of construction and/or methods of fabrication played a major role in final selection of components.

Initially the methods of fabrication were not considered, but as the facility developed it became apparent that this criteria needed to be considered. An example of this is the run line flow control valve. The valve has a forged stainless steel body, and as such, the surface of the metal was impregnated with contamination type material. This contaminate was dislodged as the surface material was etched during the passivation step of the cleaning procedure. The original passivation step required a 2 hour exposure to Nitric acid. This resulted in the valve body exhibiting surface rust by the time the valve was ready for installation. Final resolution with this valve required the disassembly, machining, and polishing of the internal surfaces to obtain the proper finish. This problem is addressed later as a lesson learned.

A turbine flow meter is an example of a problem encountered with a component which is fully compatible with respect to all materials of construction, but operationally experienced anomalies resulting from construction materials. The metal materials of construction for the flow meter are stainless steel, which created problems with the magnetic pick-up for the turbine flow meter.

The procured run line isolation valves presented another challenge. The valves were fully compatible from a compatibility concern, but the configuration was not the most desirable for use in peroxide. The valves selected were ball valves with the balls drilled on the upstream side to prevent entrapment and subsequent decomposition. However, the valves were also procured as cryogenic valves, with extended stems, for possible future cryogenic use. The extended stem configuration presented a possible leak path for the peroxide to enter the stem. Therefore these valves and valve stem components were carefully cleaned and all materials selected for compatibility.

Figure 3 illustrates the orientation concern for the main H_2O_2 isolation valve being installed horizontal. This configuration has potential for peroxide to migrate into the cryogenic stem cavity and be subjected to decomposition.

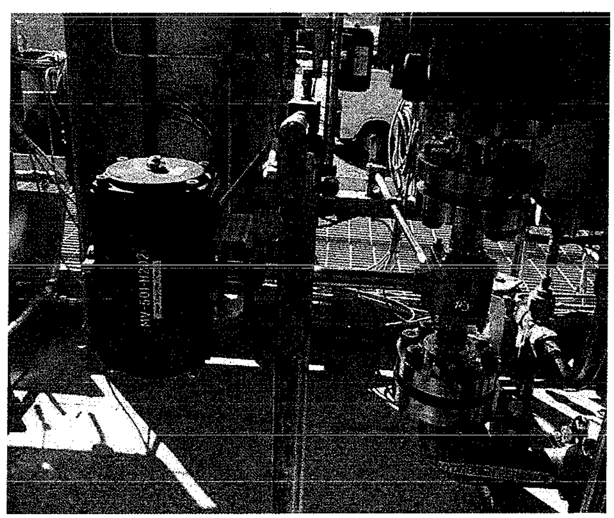

Figure 3. Peroxide Run Tank Isolation Valve Orientation

The peroxide transfer pump selected is a double-diaphram pump, with all materials on both sides of the diaphragm seals being compatible with 85% peroxide. The pump is an all stainless steel and teflon food-grade pump as shown in Figure 4. The pump is mounted over a stainless steel catch basin, which is partially filled with water for dilution of any residual peroxide drained from the pump.

The remainder of the components used for the run system and all interfacing systems or components are 300 series, stainless steel with teflon soft goods, where applicable and/or available.

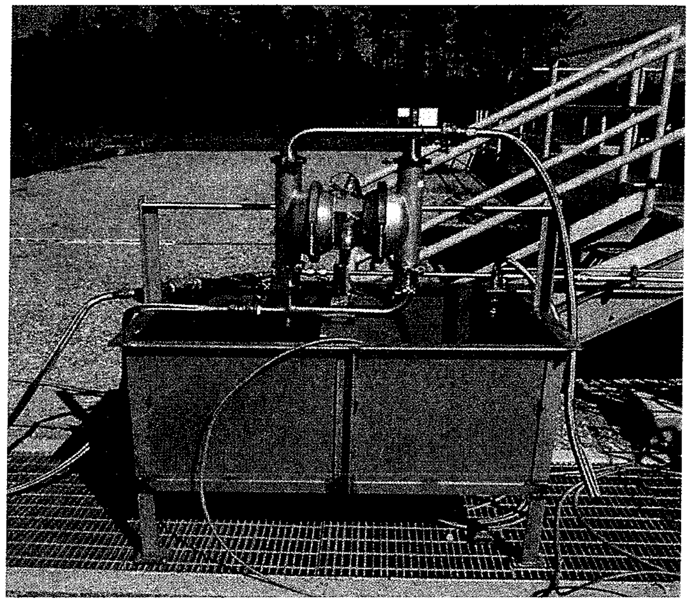

Figure 4. H_2O_2 Transfer Pump & Catch Basin

<u>Cleanliness</u>

The cleanliness issue was a major factor from the aspect of contamination inducing a decomposition process. The industry standard guideline for exposure to high-test peroxide requires a nominal 2-hour passivation of 300 series stainless steel with a Nitric acid solution. This process was initially incorporated into the SSC cleaning operations. However, as components exposed to this extended acid soak were installed, it became apparent the additional acid soak was etching the surface material and significantly increasing the occurrence of stainless steel threads galling during installation.

The standard cleaning process at SSC is designed to meet oxygen cleanliness requirements established by SSC Standard 79-001, Level 1XX. The SSC oxygen cleaning process exposes the metal parts to a minimum acid passivation soak of 15 minutes in a 27%-34% Nitric acid at 85°F. The modification made to SSC's cleaning procedure for the peroxide requirement, is to increase the acid solution exposure time from 15 minutes to 1.5-2-hours. A preliminary "rough" test was conducted with components from each of the passivation processes (15 min. Vs 2 hrs.), exposed to 70% peroxide. No significant difference was observed in the reactions generated from either component. Therefore, the decision was made to delete the extended acid passivation exposure and use the SSC standard cleaning procedure for oxygen service items.

The rationale for deleting the extended acid passivation exposure considered additional factors such as: 1) the test stand had been initially designed for a single project use, 2) the ground-rule that the peroxide run system would not be utilized for storage, and 3) system design and instrumentation requirements contained numerous threaded fittings, which were adversely affected by the extended passivation exposure. The quantity of threaded fittings would not be recommended for a system exposed to continuous peroxide environments.

Another related factor was that the lubricant recommended did not provide sufficient lubricity to minimize the stainless steel thread galling potential, without coating threads with an excess quantity of lubricant. The excessive quantity of lubricant presented additional anomalies for test articles and is discussed further in the lessons learned section. The allowable lubricant was changed from silicone grease to halocarbon grease, such as used throughout SSC's oxygen systems. To date, approximately 40,000 lbs of 85% peroxide has been flowed through the facility systems with no pre-mature decomposition or adverse reactions to the systems or test articles observed.

Operational Information

The actual operational processes and procedures are fairly lengthy and specific to the E3 test facility. The following is provided as a generalized timeline/sequence of events for a typical test day.

Typical Test Day Sequence of Events

- **Facility mechanical and electrical system checkouts (2 hrs)**

During this step, test team personnel verify valve configurations, set up the pressure regulators, start the control and data systems, verify calibration of transducers, verify valve functionality by cycling the valves, etc. Additionally, site pressures, propellant levels, etc. are verified and recorded.

- **Pre-test calibration of thrust measurement system** (1 hr)

A series of known forces are applied to the thrust measurement system to calibrate the system for the pending test. This calibration evaluates the system's zero repeatability, tare influences and offsets. Figure 5 illustrates a test configuration with the TMS installed.

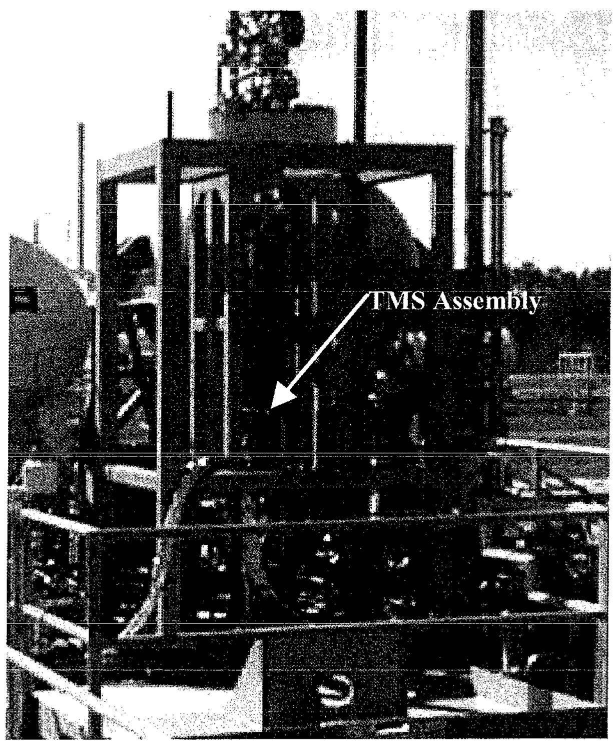

Figure 5. TMS Installed in Vertical Position

- **Load H_2O_2 into the Run Tank from ISO Container or Drums** (1 hr)

Either an ISO Container or individual drums of H_2O_2 are moved from a storage area to the test cell. Personnel don their PPE (PVC Rain Suit, PVC boots, nitrile gloves, chemical goggles and hard hat with face shield), and prepare for the fluid transfer to the run tank. Transfer hoses are connected and a predetermined amount of H_2O_2 is pumped into the 500 gal run tank using a H_2O_2 compatible double diaphragm pump. At completion of the transfer, the pump and fill hoses are rinsed with 15 meg-ohm DI water and purged with gaseous nitrogen. The ISO Container or drums are returned to the H_2O_2 storage area. Figure 6 shows the H_2O_2 transfer operation from the ISO container to the run tank.

- **Button-up Procedure** (30 min)

The Test Conductor verifies final valve configuration in the test cell. Tank and purge pressures are set for test. Manual isolation valves on run lines are opened. Test cell is evacuated and spotters are set up at the test complex perimeter.

- **Firing Check List and Hot Fire Test** (Time dependent on number of tests)

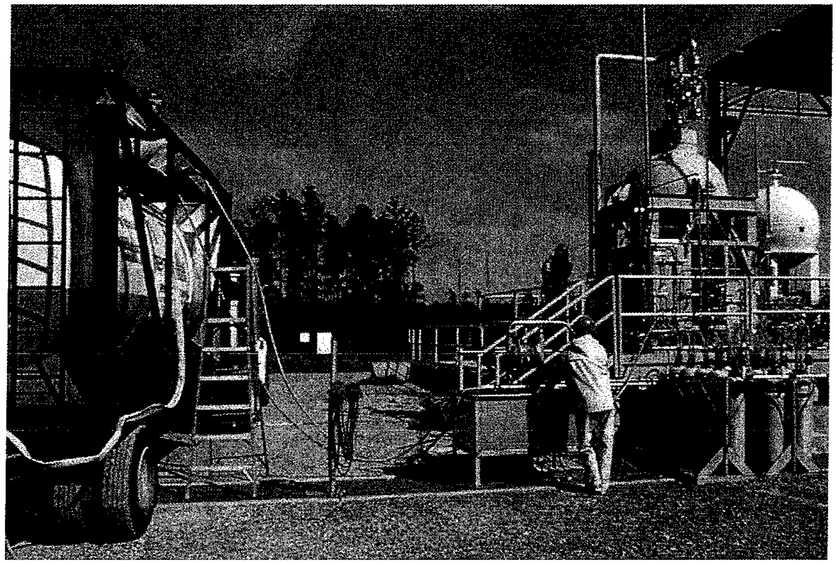

Figure 6. Typical Tanking Operation

Test Conductor polls test team for readiness, verifies the area is clear, and instructs console operators to begin recording data. The run tanks are pressurized and with customer concurrence the test countdown is initiated.

Post- test, the run tanks are depressurized and the facility and test article is safed from the test control room.

- **Post-test facility securing (1hr)**

Using a handheld peroxide % concentration monitor, test team personnel are allowed back into the test area to reconfigure the system for additional hot fire test or to secure the facility for the day. The facility is safed by dumping any residual peroxide to the facility catalyst bed shown in Figure 7. All actuation pressure and purges are vented down. Handrails and test platform are washed with potable water to dilute any potential H_2O_2 mist that may have accumulated on the facility. Access is allowed to the customer for visual inspection of the test article. Also during this time, data processing is being performed.

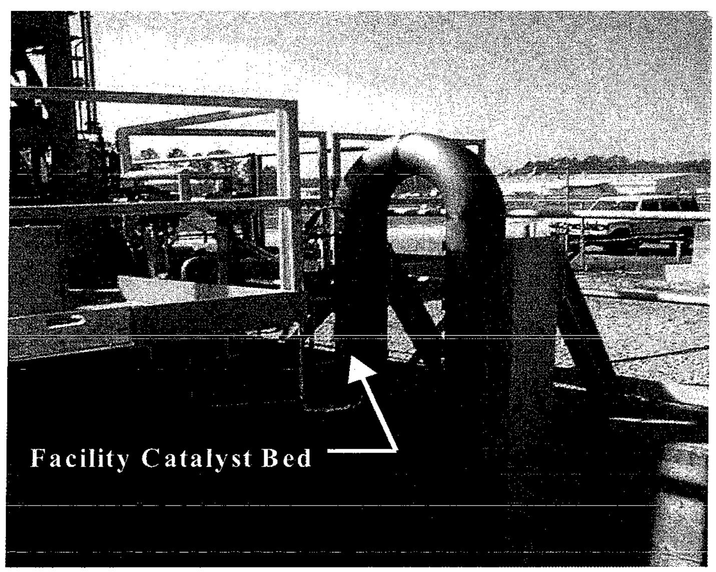

Figure 7. Facility Catalyst Bed - Low Flow Operation for Safing Facility

- **Post-test calibration of thrust measurement system (1 hr)**

The thrust measurement system is checked to verify it is still operating properly. Calibration loads from the pre-test sequence are applied and corresponding data recorded and evaluated.

- **End of test day**

Lessons Learned

The development and operation of a peroxide facility of this size and capability generated numerous lessons learned for the E3 Test Team. The following are submitted for reference and as guidelines for anyone considering developing a test capability. These lessons learned are intended to assist industry in mitigating problems and identifying potential pitfalls when dealing with the requirements for handling high-test peroxide.

1. *Occurren*ce - Component Selection(s): A seal ring installed on the main H_2O_2 run tank is coated with a marginally compatible coating. The coating exhibits minor decomposition reactions with the peroxide. The associated risks have been evaluated and determined to be acceptable to the current and planned projects/ efforts within Cell 2, based upon ground-rule previously stated of minimizing exposure of the run tank.

Ball valves selected for the project were procured to industry specifications for hydrogen peroxide service with one exception. In an effort to expand the capabilities of the procured valves to future programs, the valves were procured for cryogenic service. Although acceptable for use in H_2O_2 service, the extended stems provide an undesirable area in which peroxide could become trapped and decompose over time.

It was discovered during the cleaning / passivation process that the stem of the main flow control valve for the H_2O_2 system was coated by a hard-faced material that was incompatible with H_2O_2.

A flow control valve from another facility at SSC was selected as the H_2O_2 main flow control valve. This particular valve's body was a forged item and as such, presented several problems when it came to cleaning for H_2O_2 service. Iron deposits either from contaminated sand casts or contaminated blasting media resulted in corrosion spots over the entire valve body upon cleaning and passivation. Ultimately, the valve had to be polished and treated with a strong acid etching paste to remove impurities from welded areas.

Lesson Learned: Thoroughly evaluate a component's materials of construction compatibility, manufacturing process, and intended use as it applies to the peroxide application prior to considering multiple usage scenarios.

2. *Occurrence* - H_2O_2 Inhalation Exposure: H_2O_2 passing through catalyst beds result in clouds/mists of unknown composition peroxide that pose a risk to personnel from inhaling. A Stennis engineer was exposed to peroxide vapors in close proximity to the cell immediately

following a test firing. The engineer felt oxygen deficient and was transported to the hospital for examination. After determination that no injury had occurred, the engineer was released.

Lesson Learned: Either area wide monitoring or portable monitoring devices must be obtained to measure the concentration of peroxide in air following tests or decomposition of H_2O_2 in facility catalyst beds. SSC obtained a portable, air-monitoring device, which provides real time readings of H_2O_2 concentration in air. This unit is now used anytime personnel must enter the area following release of H_2O_2 vapors into the air.

3. *Occurrence* – Galling of threads and excessive Grease/Lubricant: Facility system design and instrumentation requirements contained numerous threaded fittings, which were adversely affected by the extended passivation exposure. The recommended cleaning process included a 2 hour acid passivation, which resulted in threaded and sealing surfaces becoming etched. As components exposed to this extended acid soak were installed, it became apparent the additional acid soak was etching the surface material and significantly increasing the occurrence of stainless steel threads galling. Therefore, additional lubricant was used during assembly and resulted in surplus lubricant being injected into the system as connections were made or broken. This "surplus" grease was compatible with the peroxide, but potentially could have had detrimental effects on test articles downstream.

Lesson Learned: Several lessons were involved with this issue. First, the cleaning process was modified to eliminate the additional acid passivation (acceptable for the stated applications) to minimize the surface etching effects. Secondly, the lubricant was changed from an industry acceptable silicone lubricant to a lubricant used in-house for oxygen service hardware. Thirdly, the work practices were reviewed and personnel instructed to apply lubricant in accordance with standard oxygen service applications. More is not always better.

4. *Occurrence* - H_2O_2 Contamination of Cabling: Peroxide mists of unknown concentration from the tests and passage of H_2O_2 through the facility catalyst bed settled out over the test stands. H_2O_2 from these clouds / mists became trapped within the taped up cable connectors and technicians came into contact with this upon removal of connectors.

Lesson Learned: Personnel to wear gloves and eye protection whenever working on any system exposed to H_2O_2 mists.

5. *Occurrence* - Galvanic Corrosion of aluminum seals: All tubing connections on the test stand used 37° flared fittings. Aluminum flare seals were initially procured in lieu of stainless steel to meet project schedules. Galvanic corrosion set up between the aluminum seals and the stainless steel tubing used in the system. The aluminum seals corroded and formed aluminum oxides. Although this oxide is not detrimental to the peroxide, it does present a problem when breaking and entering into the systems, and degrades sealing properties.

Lesson Learned: Evaluate piping and tubing needs early in a H_2O_2 project and place orders for special items early.

6. *Occurrence* - Trapped H_2O_2 within the pumping cavities of the double diaphragm pump used to transfer the peroxide: The design of the diaphragm pump allowed for trapping of H_2O_2 within the main pump cavities and manifolds of the pump.

<u>*Lesson Learned*</u>: Prior to placement in service, evaluate the configuration of all components for potential peroxide traps or incompatibility. The pump was modified to include drain ports on both the inlet and outlet manifolds of the pump. In addition the pump was mounted so that it could be rotated to aid in draining the pump following transfer.

7. *Occurrence* - Implementation of OSHA Process Safety Management: It was realized early in the facility development that OSHA Process Safety Management regulations were applicable. The quantity located on-site would require SSC to implement the requirements of this federal regulation.

<u>*Lesson Learned*</u>: Many of the unique OSHA requirements were already being met by existing projects and processes at SSC and only required documentation. The implementation of this approach increased test team awareness and familiarity with the new facility's operation, hazards, and processes. Increased ownership of the test process by all members of the Team resulted.

8. *Occurrence* - Personnel inexperienced with H_2O_2: SSC employees entered into this effort with no experience in handling H_2O_2 or design/fabrication of such a stand.

<u>*Lesson Learned*</u>: The E3 Team relied heavily on the provider of the peroxide to aid in the design and selection of components for the facility. Safety guidance and training was provided by both the peroxide manufacturer and a consultant experienced with peroxide production, handling, and testing.

9. *Occurrence* - Entrapment of H_2O_2 in instrumentation: It was determined that entrapment of peroxide in the system's instrumentation would pose a hazard to personnel when breaking and entering the system.

<u>*Lesson Learned*</u>: Pressure transducers were purchased with flush faces to preclude the entrapment of H_2O_2. Instrumentation legs were plumbed vertically or sloped downwards away from the instrument to facilitate drainage of the peroxide back into main run lines. Where possible, thermo-wells were used to isolate temperature sensing devices and aid in the servicing of these. Lines were carefully routed to facilitate drainage within the entire system.

Facility Utilization

The utilization of the E3 high-test peroxide test facility has exceeded all initial expectations. The facility was developed to support one (1) primary test program, but the capability and design has been flexible enough to currently be supporting numerous programs, test articles, requirements, and configurations. The following is a brief summary of the programs, which have utilized this facility, those currently in the facility, and future programs committed to using the facility.

The Upper Stage Flight Experiment (USFE) Program, Phase 1, by Orbital Sciences Corporation was the first program to utilize the E3, Cell 2, test facility. The USFE program utilized a pressurized feed system for 85% H_2O_2 and JP-8 as its propellants. This program conducted both mono-propellant and bi-propellant tests in the evaluation of their catalyst bed and fuel injection systems. The testing ranged from low flow conditions up to nominal flows in the 30-40 lbm/sec and culminated with a successful nominal flow bi-propellant test for 140 seconds duration. Figure 8 is a view of the USFE engine firing into the E3 Cell 2, flame bucket.

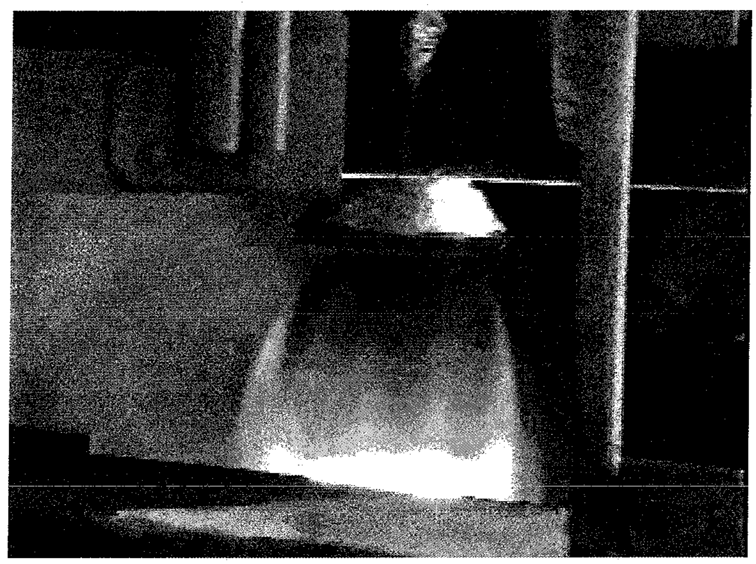

Figure 8. USFE Bi-Propellant Engine Test

The USFE program was followed by the Boeing AR2-3 test program of their previously flight proven system. The AR2-3 test article is a pump-fed system, thus requiring the facility to be slightly modified to accommodate the low pressure run systems. Initial testing started with mono-propellant tests using 85% and 89% peroxide. Bi-propellant tests are upcoming with JP-8 as the fuel and both 85% and 89.2% peroxide. Other hydrocarbon fuels may be possible candidates for use. The inclusion of these additional fuels will be determined upon program requirements and facility handling capability and compatibility of materials of construction utilized in the existing fuel systems. The USFE and AR2-3 programs have used the vertical firing position with and without the available thrust measurement system.

A concurrent test program to the AR2-3 program is a catalyst bed development program by Pratt & Whitney. The implementation of this program along with the AR2-3 required the modification of Cell 2 to include a 2nd test position. Therefore, a horizontal firing position was incorporated to handle component level tests. This horizontal firing position utilizes the existing propellant run systems and is reduced to the low flow requirements by means of cavitating venturis between the facility interface and the test article. Testing for this program is schedule to begin in November 1999.

The immediate future for the test facility includes a return of the USFE program for additional follow-on testing. There is also a peroxide hybrid test program for Lockheed Martin scheduled for early 2000, which will require additional modifications to the existing test stand to accommodate a horizontal firing position capable of a minimum of 10,000 lbf thrust. The modifications required for the increased horizontal capabilities will be modular in design to maintain the capabilities of the vertical position as well. Additional component testing is also planned for support of Boeing's development of a catalyst bed and turbopump assembly. There are also potential plans for additional subscale testing efforts and follow-on testing for existing programs currently utilizing the E3 high-test peroxide capabilities.

Addendum –1

Facility Description

The following facility description is provided as additional detailed information form the SSC Facility Capability Document for the E3 Test Stand.[1] The E-3 Test Facility is a versatile test complex that is available for component development testing of combustion devices, rocket engine components and small/subscale complete engines and boosters. The facility has the capacity to deliver propellants at low and medium pressures. Figure A-1 illustrates a basic schematic configuration of the test stand. All propellant storage, transfer, and run systems for H_2O_2 are cleaned to Stennis Space Center (SSC) STD 79-001, cleanliness level 1XX. This cleanliness level is essentially the nominal cleanliness level for facility LOX and GOX systems throughout the Center's facilities.

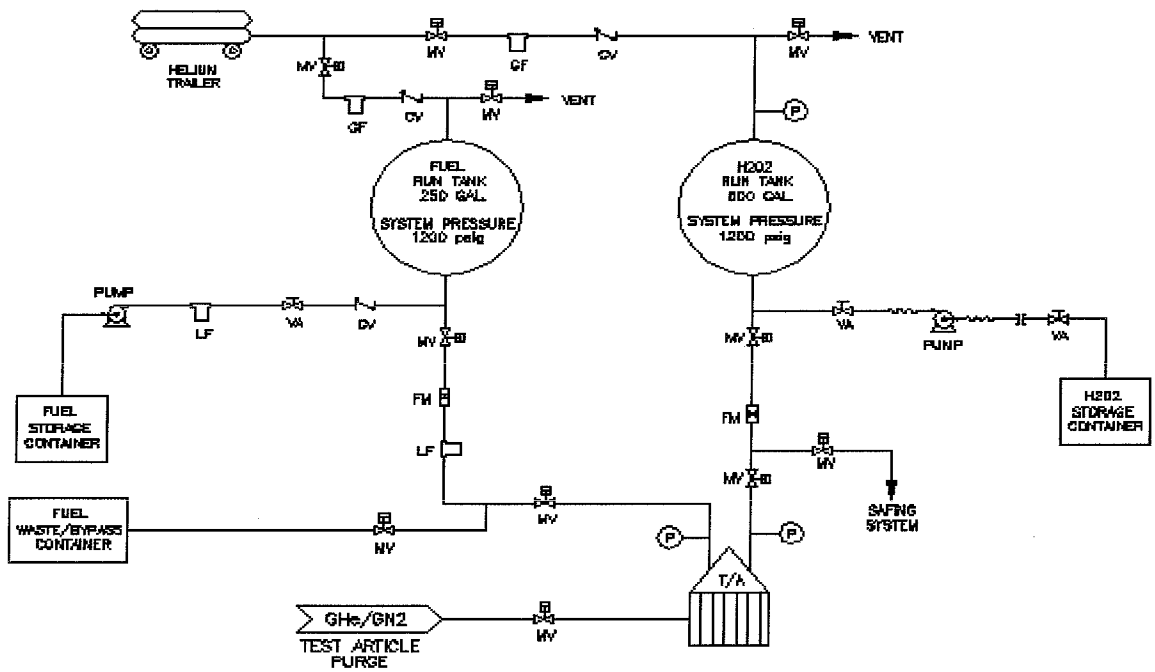

Figure A-1. Test Cell Schematic

Cell 2 is primarily designed to test pressure-fed H_2O_2/hydrocarbon fuel, and H_2O_2/hybrid rocket motor combustion devices up to 25,000 lbf of vertical thrust (50,000 lbf impulse load). At present, Cell 2 is configured to support testing of a 10,000 lbf H_2O_2/JP-8 engine. Two vertical thrust takeout structures are available that mount above the flame bucket access hole. One can be outfitted with the single axis TMS, whereas the other is shorter and stiffer but does not have TMS capability. The current engine test program is using the available single-axis 10,000 lbf thrust measurement system (TMS) as installed in the vertical position.

Cell 2 features a skid based design concept. In this concept all test specific hardware (run tanks, run lines, and test article) are mounted to a platform that is then bolted above an existing 8 ft. wide by 17 ft. deep concrete flame bucket. The existing platform contains a 500 gallon oxidizer run tank and a 250 gallon fuel run tank. These are mounted next to each other on the south side of a 48 in. by 48 in. flame bucket access hole provided for the test article. Table A-1 outlines the existing commodity supply capabilities for Cell 2.

Table A-1. Cell 2 Commodity Supply Capabilities

Propellant	Press. (psig)	Temp. (°R / °F)	Flow Rate (lbm/sec)	Supply Line
H2O2	1200	540 / 80	48	2”
JP-8	1400	540 / 80	15	1”

The flame bucket on Cell 2 can be utilized for confinement of propellants discharged from either the cell facilities or through the test articles. The facility power system provides single and three-phase power at 480VAC, 277VAC, 208VAC, 220VAC, and 120VAC. Un-interruptable power supply (UPS) systems provide 120VAC power to test critical systems. 28V DC is provided for control system I/O and as required for test article power. A mobile crane provides lifting capability. There is no overhead roof on Cell 2.

An isolated 30 ft. by 35 ft. area surrounded by a 2 ft. high earthen berm is located East of the test cells for the storage of H2O2.

Control System

The E3 Test Control Center (TCC), located in the E-Complex Test Operations Building (TOB), houses the control system equipment, and serves as the central command location for the test conductor and test personnel during test operations. The control system is a PC and National Instruments (NI) based system that provides control of the facility, pretest setup, run-time displays, automated facility monitoring, and shutdown. The system provides real-time control of the test article (if requested by customer), propellants and valve schedules. Toggle switches are used to control power supplies, etc; and as shutdown control devices outside of the PC/NI based control system.

Instrumentation

Facility instrumentation is installed for real-time display of facility processes and data recording. Instrumentation provided or recorded for the test article is determined with each customer. The facility also provides the ability to display real-time test article measurements. Instruments that provide test article response information, time critical control functions, or are located at facility to test article interfaces have a typical response of 350 ms.

Up to 48 channels of general-purpose signal conditioning are available to excite, amplify, and filter a variety of sensors in the test cell. Up to 32 channels of standard thermocouple signal conditioning is also available.

Data Acquisition System

The data acquisition system is divided into low-speed and high-speed systems. Each system can support a limited number of data channels. The low-speed data acquisition system (LSDAS) can accept up to 80 analog input channels for a total throughput of 1,200 sps of 12 bit data. Data is recorded remotely in the TCC. The LSDAS uncertainty is expected to be better than ±0.2%, excluding instrumentation and associated cabling. The LSDAS provides a real-time display with a refresh rate of 15 cycles per second. Real-time calculated value capability is available.

The high-speed data acquisition system (HSDAS) provides 20 analog input channels with a throughput of up to 80,000 sps per channel of 16 bit data. This capability can be expanded to 30 channels, as data-conditioning equipment becomes available. Discrete channels can be substituted for the existing analog channels as required. One channel is presently reserved for IRIG B time recording. The data is recorded digitally on Super VHS tape.

An additional data acquisition system is the E3 video capabilities. E3 utilizes four low speed video cameras for normal testing. Each camera has pan, zoom, focus, iris, and tilt capabilities. The camera enclosures, boxes, and conduits are purged with GN to maintain compliance with the appropriate electrical hazardous classification requirements. Three cameras are permanently mounted to the canopy columns of the adjoining Cell 1. A fourth camera is portable for placement as desired to capture significant events not covered with the three overhead-looking cameras.

Data Processing

Data processing is provided for the LSDAS and HSDAS. The LSDAS data is converted to Engineering Units and processed into a standard file format utilized in the E-complex. The LSDAS data file can be provided in an ASCII format. A measurement and calculated values plotting program is available. A quick-look program is also available for on-line analysis. Data backup for LSDAS is provided on JAZZ cartridges.

The HSDAS data is generally filtered and sub-sampled to 5 kHz. The data is then processed to Fast Fourier Transforms (FFT) for frequency analysis. A quick-look dynamic analysis program is available for data reports and quick-look. Data backup is provided on CD-ROM and/or DAT tape.

Off-site data transfer is available for both systems through the Internet or FTP link.

Facility/Test Article Protection

E3 uses a 6 in. potable water system for the purpose of providing deluge cooling water and limiting damage in the event of a fire in a test cell or propellant storage/handling area. The system includes spray nozzles installed on the roof of Cell 1 and two water cannons situated between Cell 1 and Cell 2. The E3 deluge system covers the following areas: all test cells, all oxidizer vessels, all fuel vessels, and all tanker fill headers. All areas can be remotely operated from the control room. In addition, the two water cannons can be locally operated.

Plume Impingement Area

Plume impingement area is provided for Cell 2. The plume impingement area features thrust deflectors that are made of concrete ablative material for the purpose of minimizing the effects of heat and acoustic loads generated by a combustion device plume. The material has the following thermal properties; service temperature 10,000°F, exposure temperature 20,000 °F, and melting temperature 23,000 °F. In Cell 2, the plume is directed first downward into the flame bucket and then redirected northward. The plume impingement area at the bottom of the flame bucket is sloped for this purpose. A new deflector with associated enhancements for turning angles and cell protection is currently being installed for support of future and long duration firing programs.

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R. Bruce, G. Taylor, D. Beckmeyer, S. Warren, S. Dracon, B. Powell, D. Goodwin, P. Rieder (all NASA); R. Nichols (Lockheed Martin Space Operations, Stennis Program)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Propulsion Test Directorate
John C. Stennis Space Center
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Renewed interest in high-test peroxide, as a propellant, required the development of a facility capable of testing rocket propulsion systems. The development of this capability at the NASA Stennis Space Center (SSC), MS, focused on meeting this requirement. The challenges, accomplishments, and lessons learned associated with developing the SSC E3 Test Facility's high-test peroxide capability are presented herein.

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