Conf-940812--4

LA-UR-94-1688

Title: AN OVERVIEW OF THE NUCLEAR ELECTRIC PROPULSION SPACE TEST PROGRAM (NEPSTP) SATELLITE

Author(s): Susan S. Voss
Edward L. Reynolds

Submitted to: 29th IECEC Conference
August 7-12, 1994
Monterey, CA

MASTER

Los Alamos
NATIONAL LABORATORY

Form No. 836 R5
ST 2629 10/91

DISCLAIMER

AN OVERVIEW OF THE NUCLEAR ELECTRIC PROPULSION SPACE TEST PROGRAM (NEPSTP) SATELLITE

Susan S. Voss
Los Alamos National Laboratory
MS D466
Los Alamos, New Mexico 87545

Edward L. Reynolds
Applied Physics Laboratory
23-336 John Hopkins Road
Laurel, Maryland 20723

Abstract

Early in 1992 the idea of purchasing a Russian designed and fabricated space reactor power system and integrating it with a U.S. designed satellite went from fiction to reality with the purchase of the first two Topaz II reactors by the Strategic Defense Initiative Organization (now the Ballistic Missile Defense Organization (BMDO)). The New Mexico Alliance was formed to establish a ground test facility in which to perform nonnuclear systems testing of the Topaz II, and to evaluate the Topaz II system for flight testing with respect to safety, performance, and operability. In conjunction, SDIO requested that the Applied Physics Laboratory in Laurel, MD propose a mission and design a satellite in which the Topaz II could be used as the power source. The outcome of these two activities was the design of the Nuclear Electric Propulsion Space Test Program (NEPSTP) satellite which combines a modified Russian Topaz II power system with a U.S. designed satellite to achieve a specified mission. Due to funding reduction within the SDIO, the Topaz II flight program was postponed indefinitely at the end of Fiscal Year 1993. The purpose of this paper is to present an overview of the NEPSTP mission and the satellite design at the time the flight program ended.

Introduction

The TOPAZ II single-cell thermionic space power system has evolved significantly since its start in the early 1960s. Beginning with the first electric ground test in 1971, the system continually evolved until the Soviet government ended the program in 1989. The goal of the TOPAZ II program was to develop a flight qualified power system capable of meeting the performance requirements of its customer. TOPAZ is a Russian acronym for Thermionic Experiment with Conversion in Active Zone. TOPAZ II was a secret military program, and was never flown.

Near the end of the 1980s, the Russians approached a private U.S. company regarding the possible purchase of Russian space reactor hardware. The negotiations led to the U.S. actually purchasing two TOPAZ II units and associated ground test hardware, and the initiation of the Nuclear Electric Propulsion Space Test Program (NEPSTP) mission by the Strategic Defense Initiative Organization (SDIO)[1].

The New Mexico Research Alliance (NMERI) was formed in Albuquerque, NM consisting of members from the University of New Mexico, Los Alamos National Laboratory, Air Force Phillips Laboratory, and Sandia National Laboratories to investigate the Topaz II reactor system. The Applied Physics Laboratory (APL) near Baltimore, MD was tasked to determine if it would be possible to integrate the Topaz II with a U.S. spacecraft using electric propulsion and launch it within the U.S.

There are several benefits in doing the NEPSTP mission. As space systems develop, there is a growing need for new power sources to meet growing power requirements. In many cases, the use of solar array power or Radioisotope Thermoelectric Generator (RTG) power is just not suitable. Some satellites will require the high power capability that can be achieved only by a nuclear reactor. Before committing resources to developing these high power space assets and new reactor designs to power them, it would be wise to determine if it is still possible to obtain approval to launch a nuclear reactor system in the U.S. The safety policies and launch approval process have changed significantly since the U.S. launched the last reactor system in the mid-1960s. Though the NEPSTP mission was not completed, the program has been successful in identifying the issues to launch a nuclear reactor system given the current U.S. safety and launch requirements. It also identified what modifications to the Topaz II were required to meet those safety requirements and launch requirements.

Another benefit of the NEPSTP mission is the evaluation of new electric propulsion technologies. Currently there are a handful of new electric thruster designs that have been developed but have never been tested in orbit. Electric thrusters are attractive to future space missions because of their high propulsion efficiency (specific impulse). The high efficiency allows more payload mass to be used for actual payload instead of propellant. Future space missions can use electric propulsion to perform orbit adjust maneuvers such as orbit raising, station keeping, change of inclination or node, etc. Another use of electric propulsion is the ability to 'randomize' the orbits of space-based assets. By constantly thrusting at low levels, the ability of an adversary to predict the location of the satellite is close to impossible. In addition to serving as a test bed for these thrusters, the NEPSTP mission could develop the actual techniques to perform these maneuvers with a low thrust system.

Both the space nuclear reactor and the electric thrusters are known to generate electromagnetic fields around themselves and to alter the natural space environment. As these systems develop in the future, the electronics of the host spacecraft will have to be designed to tolerate these fields. With NEPSTP and its suite of measurement instruments, these field measurements can be taken while the reactor system and the electric thrusters are operating to develop an environment data-base that can be used for future designers.

The U.S. has tested two systems at the Thermionic System Evaluation Test (TSET) in Albuquerque using Russian test hardware integrated with U.S. hardware. The U.S. has also purchased four additional systems, two of which are potential flight units. Due to funding reduction within the BMDO, the Topaz II flight program was postponed indefinitely at the end of Fiscal Year (FY) 1993.

The purpose of this paper is to provide an overview of the NEPSTP mission requirements and goals, an overview of the proposed mission scenario, and description of the satellite design. Due to the TOPAZ II reactor system's central role for this mission, special emphasis is given in the satellite description over other spacecraft subsystems. The paper also includes a description of the development testing of the reactor system.

NEPSTP Mission Requirements

The NEPSTP mission was designed to meet the following mission requirements:

First, the mission must evaluate the performance of Russian Topaz reactor system. This includes power generation, operation, and long-term trends. The spacecraft can monitor the reactor system by several methods. The output power is measured using a current sensing shunt and bus voltage monitoring. Other measured reactor system parameters include: temperatures, pressures, neutron flux and the position of the control drum. This information is telemetered to the ground and stored in a mission data-base. Using the data-base, long-term trending information can be analyzed to ascertain the degradation of the system.

A second requirement of the mission is to evaluate the different electric thrusters (ion, stationary plasma, hall, etc.) and the different propulsion techniques. The thrusters will be life tested, each powered for periods of thousands of hours. The measurable parameters are the thrust acceleration, power loads, propellant consumption, as well as housekeeping parameters such as temperatures and voltages. The thrusters will be used to test techniques to change altitude, inclination, and orbit node. Methods to improve these techniques will also be investigated.

The third requirement is to measure the induced environment caused by the reactor system and the thrusters. A set of eight instruments will be used to measure the environment within the spacecraft and also surrounding the spacecraft.

Given the mission developed, if any science of opportunity can be performed it to is to be pursued. The NEPSTP mission would pass through a large range of altitude from 3500 kilometers to over 40,000 kilometers traveling a slow spiral. Such a trajectory is ideal for performing magnetosphere measurements.

APL was directed by the sponsor to use a U.S. launch vehicle, therefore the Delta, Atlas and Titan II were evaluated. To ensure the reactor system would not reenter until the level of radioactivity was below the actinide level, the satellite was to be placed in a 700 year orbit. Other issues associated with interference of other scientific satellites drove the required orbit altitude higher to 3500 km. A circular orbit was planned do to its to do long-term orbit stability predictions.

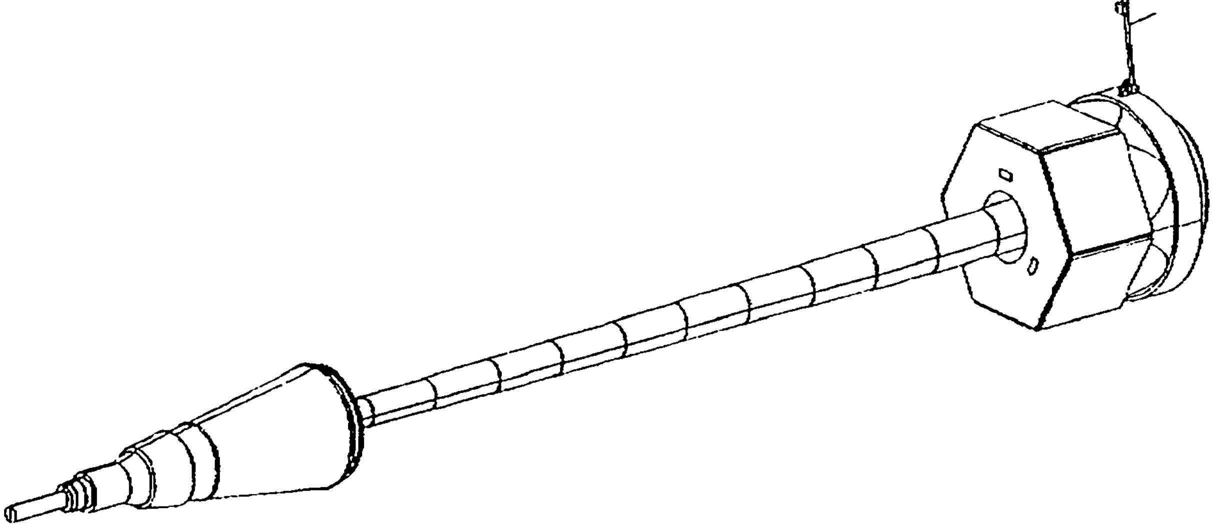


Figure 1: The NEPSTP Satellite Deployed.

Functional safety requirements were developed for reactor startup, inadvertent criticality, radiological release during routine operation, disposal, inadvertent reentry, and safeguards. A total of eighteen flight safety and protection function requirements were established for the NEPSTP flight test[2].

Satellite Overview

The NEPSTP has two primary subsystems: the Topaz II reactor subsystem and the spacecraft subsystem. The two subsystems are separated by a separation boom that extends after the satellite is injected into orbit. Figure 1 is a schematic of the deployed NEPSTP spacecraft. Given the limited payload volume of the available U.S. launchers, the reactor subsystem had to be launched upright, that is with the reactor core at the top of the launch vehicle, to take advantage of the tapered rocket nose cone. A brief overview of these two subsystems is provided below.

Topaz II Reactor Subsystem Description

Topaz II Reactor Subsystem Overview and Description

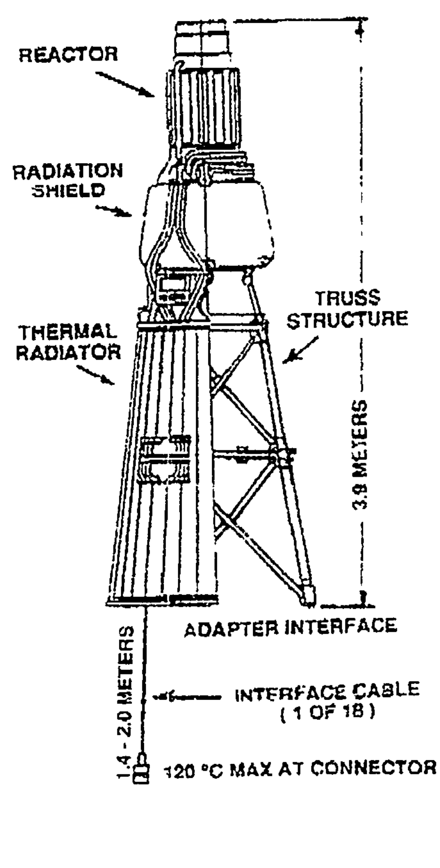
During the development of the Russian TOPAZ II the mission changed several times. This impacted the power level, lifetime, satellite radiation levels, and launch configuration. But the mission changes had little effect on the system safety and the proposed operating orbit. Therefore, the Russians were able to tailor the safety requirements and the system design to a limited set of technical specifications. Their final design requirements specified a nuclear reactor system that would produce 4.5 to 5.5 kWe at 27 volts for 3 years. The Russians specialists had a design goal for system reliability and operation of greater than 95% probability. The intended missions specified operation in a geosyncronous Earth orbit (GEO). They were given an exact mass constraint of 1061 kilograms for the reactor system (not including the reactor control unit), and radiation limits to the spacecraft bus of 1×10^{11} neutrons/cm^2 for neutrons of energy greater than 0.1 MeV and a gamma dose of 5×10^4 roentgen. The mission profiles helped to limit the number of overall safety requirements by providing a very prescribed operating basis[4].

The TOPAZ II is a single-cell thermionic reactor system. The nominal reactor thermal power is 115 kWth and the maximum operational thermal power is 135 kWth. The thermionic fuel elements (TFE) have an average conversion efficiency of 5%. The Topaz II system is shown in Figure 2 .

Figure 2: The Topaz II Reactor Subsystem.

The nuclear reactor contains 37 TFEs that are fueled by UO_2 fuel pellets 96% enriched in

Figure 2


REACTOR
RADIATION SHIELD
TRUSS STRUCTURE
THERMAL RADIATOR
3.9 METERS
ADAPTER INTERFACE
1.4 - 2.0 METERS
INTERFACE CABLE (1 OF 18)
120 °C MAX AT CONNECTOR

Uranium-235. The reactor contains approximately 27 kg of Uranium-235. Three of the TFEs are used to power the electromagnetic (EM) pump and the remaining 34 provide power to operate the reactor system and the satellite. The TFEs are set within axial channels in five stacked $ZrH_{1.85}$ moderator blocks.

The reactor core is surrounded by radial and axial beryllium (Be) reflectors. The radial reflector contains three safety drums with independent drive motors for one-time rotation in space, and nine control drums attached to a single control drive motor located beneath the shield. Each drum contains a 116° section of boron-silicate-carbide neutron poison (0.5 mm thick) to control the nuclear reaction by drum rotation. The waste heat from the reactor is removed by the eutectic sodium-potassium (NaK) coolant. The coolant flows past the outer surface of the TFE collector boundary.

The radiation shield is attached by support legs to the lower end of the reactor. The shield is composed of a stainless steel shell that contains lithium-hydride for neutron attenuation. The stainless steel is thicker at the top and bottom of the shield and is used to attenuate the gamma radiation. The reactor coolant system includes the NaK coolant, a single EM pump, stainless steel piping, a volume accumulator, an oxygen getter, and a heat rejection radiator. The NaK coolant enters the reactor core through the lower plenum. It passes through the core and is heated from 500 to 600°C by the waste heat from the TFE. After passing through the reactor core, the coolant exits through an upper plenum and then flows through two opposite and parallel paths to the radiator inlet collector. The radiator consists of inlet and outlet collectors that are connected axially by 78 small coolant tubes. Thin copper fins with a high-emissivity coating are attached to the outside of the coolant tubes. After flowing through the radiator, the coolant flows through two return coolant paths. The EM pump, located on top of the radiation shield, pumps the coolant back to the reactor's lower plenum.

The cesium supply system provides cesium to the TFE interelectrode gap. Cesium suppresses the space charge that occurs near the emitters of the TFE and it increases the efficiency of the converter. During operation, the cesium from the reservoir is distributed to the TFE interelectrode gap. The cesium is vented to space at a rate of ~0.5 gm/day.

The reactor control unit provides the mechanism for monitoring, controlling and telemetering power system conditions.

Reactor Subsystem Interfaces

The Topaz II reactor subsystem has three major load bearing structures: the reactor core located at the top of the unit, the radiation shield located in the middle of the unit, and the thermal radiator and load bearing truss located at the base of the unit. For the NEPSTP spacecraft, the reactor subsystem is launched upright and the truss is part of the load bearing structure. The truss structure is a tripod frame that interfaces with three point interfaces at each end. The top of the truss interfaces with the radiation shield. The base of the truss is used as an interface to the separation boom. Any boom and adapter hardware that interfaces with this truss must withstand temperatures up to 600°C.

To interface the reactor with the spacecraft electronics, there are power and signal cables that extend approximately two meters below the radiator skirt. These cables interface with boom cables which route the signals to the spacecraft. The two meter pigtails are required to reduce the temperature of the interface connectors to 120°C when the reactor is operating. The electrical interfaces between the spacecraft and reactor system can be divided into four categories: reaction control, power, telemetry, and start-up/shut-down events. About half of the cables go to the Reactor Control Unit (RCU) and are used for the reaction control. The RCU is a microprocessor-based unit that monitors the reactor subsystem sensors and control the reactor subsystem power output by control the control drum position.

Power is transferred to the spacecraft using two '00' AWG cables. These two cables connect to the power conditioning electronics which maintains a constant electrical load on the reactor TFE working section.

The monitored telemetry includes temperatures, drum position, pressure, as well as discrete taletells. Many of the data are not used by the spacecraft control systems but are used for ground evaluation of the system. These signals are connected to the spacecraft telemetry system to be incorporated in the satellites housekeeping telemetry.

There are several cables that are used to support the startup or the emergency shutdown of the reactor subsystem. These supporting events are usually triggered by large current pulses that either fire ordnance, control relay switches, or melt bands. These current pulses are controlled by the spacecraft power switching unit with the spacecraft battery used as an energy source.

Two other components of the reactor subsystem that interface with the spacecraft are the thermal cover and the startup battery. The thermal cover blankets the reactor subsystem to conserve heat during launch and orbital injection to until the reactor subsystem begins operating. This is done to keep the NaK coolant from freezing. During reactor subsystem start-up the cover is ejected using ordnance mechanisms. The start-up battery is used to power the coolant pump during prelaunch and orbital injection to periodically circulate the NaK to avoid cold spots in the coolant system. The startup battery is used until the reactor has begun operating. Both systems are installed into the satellite during the final launch preparations, prior to encapsulating the satellite in the launch vehicle shroud. Figure 3 is a schematic of the integrated satellite prior to launch.

Figure 3: Integrated Satellite at Launch

Spacecraft System Overview

The spacecraft subsystem is divided into two main sections: the spacecraft bus and the electric propulsion module. The two sections are approximately equal in size and connect together using a simple bolt interface. The spacecraft bus is closest to the reactor subsystem and interfaces with the separation boom. The bus contains all of the electronics of the satellite with the exception of the electric thrusters and their associated power processing units.

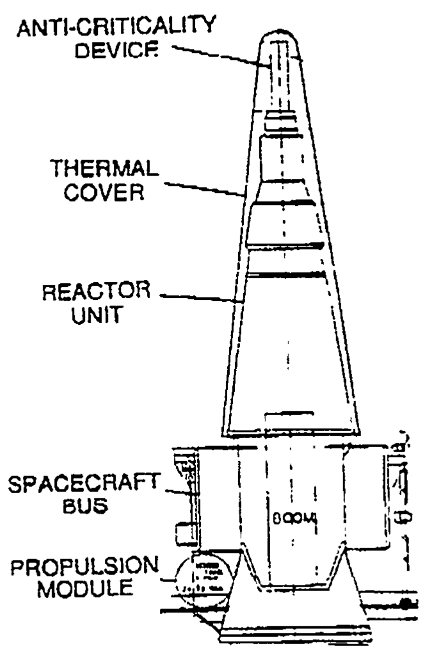
The propulsion module is at the bottom of the stack when launched and serves as the adapter interface to the launch vehicle. The propulsion module is a fully integrated propulsion system that houses 700 kilograms of xenon propellant and the electric thrusters and 'cold gas' attitude thrusters. The attitude control of the satellite is based on gimbaling the electric thrusters to provide pitch and yaw and using the cold gas thruster to provide roll capability. The electric thruster suite is mounted inside the launch vehicle adapter on a gimbaled platform. This arrangement allows the satellite to fly 'like-an-arrow' with the reactor subsystem serving as the head of the arrow and the propulsion being directed from the tail of the arrow.

During launch, the spacecraft must support the loads of the reactor subsystem. The propulsion module must support the load path of the spacecraft bus which in turn must support the load path of the reactor subsystem through its truss structure. The reactor subsystem has a majority of its mass in the core and radiation shield. When supported by the truss in an upright launch configuration, it tends to be fairly wobbly. Most launch vehicles have a payload stiffness requirement of 10 Hz or greater. The reactor subsystem alone has a fundamental frequency near 10 Hz. When coupled with the spacecraft bus, the frequency only gets lower. This requires that the spacecraft structure be as stiff as possible to avoid driving the fundamental frequency far below 10 Hz.

For NEPSTP, a cylindrical structure was selected as the structure backbone of the spacecraft subsystem; it is stiff and compatible with the launch vehicle and reactor subsystem mechanical interfaces. The separation boom and cabling (discussed below) stow in the volume inside the cylinder and the spacecraft bus electronics mounts to pallets on the outside. The cylindrical structure was adopted for the propulsion module in the form of a truncated cone. The bottom of cone serves as the interface with the launch vehicle. The top of the cone interfaces with the cylinder structure of the spacecraft bus. The interface between the cone and the cylinder uses a simple bolt interconnect.

It was envisioned that the spacecraft bus would be developed at APL. The design of the spacecraft is modular with subsystems mounted on honeycomb pallets that are supported by an

Figure 3


ANTI-CRITICALITY DEVICE
THERMAL COVER
REACTOR UNIT
SPACECRAFT BUS
PROPULSION MODULE
BOOM

aluminum frame. There are six pallets used to mount the power, attitude, command and data handling, and instrument subsystems (Figure 4). Each pallet has its own harness to connect its subsystem components together. There is also a system harness that interconnects the pallets and performs necessary functions such as safety interlocks, power distribution and system testing. Commands and data are transferred between subsystems using a MIL-STD-1553 Bus. With this partitioned approach, the subsystems can be built up and tested individually prior to integration with the other subsystems.

Figure 4: System Block Diagram.

The attitude system pallet uses star cameras and gyros for attitude knowledge and use the thruster systems of the propulsion module for attitude control. The system relies totally on the and the electric thruster for attitude control. Communication with the propulsion module uses a second MIL-STD-1553 bus.

There are two fully independent, fully redundant command systems. The normal command system (capable of performing all spacecraft functions) and the critical command system (bullet-proof but limited to commands required to start-up and shut-down the reactor). Watchdog timers are used to shut-down the electric thrusters if there is no communication with the ground for a specified period of time. The thrusters are powered off to prevent an inadvertent reentry of the reactor due to an improper thrust vector. A second watchdog timer is used to shut-down the reactor if there continues to be no communication with the ground for about 30 days.

The instruments are used to evaluate the environment around the spacecraft. The instruments are selected to characterize how the reactor and the electric thrusters alter the natural environment. The instruments are divided between an articulated science boom and the spacecraft body. The instruments selected are: an ion spectrometer, a gamma ray spectrometer, a neutron spectrometer, langmuir probes, a plasma wave spectrometer, accelerometers, contamination measurement instrumentation and total dose radiation instrumentation.

The NEPSTP spacecraft bus has two power buses: the battery bus and the reactor subsystem bus. The reactor bus receives power from the reactor power terminals and delivers power to the propulsion module, and to the spacecraft power converter input. Any excess power is shunted away using analog and digital shunts. The battery bus is a separate isolated bus that receives power from the output of the power converter and delivers power to the spacecraft loads and the reactor control electronics. The use of a battery bus isolated from the reactor bus insures that the spacecraft loads -- most importantly the RCU -- will function correctly even if the reactor power bus should start behaving erratically.

Separation Boom

A telescoping boom design was selected for NEPSTP. Early spacecraft design concepts had planar and three- dimensional scissors boom designs but they were dropped because of low torsional and lateral stiffness required by the satellite's attitude control system on orbit. Telescoping boom concepts are based on hollow concentric cylinders which are stowed one inside the other and deployed similar to a telescope. For NEPSTP, the required separation distance is ten meters. At ten meters, the total dose to the spacecraft electronics from the reactor over the one year mission lifetime is 50 krads. The spacecraft electronics are hardened to 100 krads. This leaves 50 krads dose allowance for radiation from the natural space environment. Figure 5 illustrates how the boom would be integrated with the Topaz II reactor subsystem.

The selected boom design consists of six cylinders each two meters long. A bi-stem drive mechanism in the center of the telescoping cylinders is used to extend the boom. The cylinders use special locking pins to secure each section as it is deployed, starting with the largest cylinder and working down to the smallest. All of the cylinders are aluminum except for the two closest to the reactor. These two cylinders are stainless steel which are required for the 600°C interface temperature at the reactor subsystem. The eighteen cables that connect the reactor subsystem with the spacecraft are external to the telescoping cylinders. The advantage of external cabling is it allows for easy inspection to insure proper stowage. For cable stowage during launch, pockets were positioned around the outside of the telescoping cylinders. The cables were folded in a zig-zag fashion and stowed in the pockets. At the top of each cylinder, an extended member is used to secure the cabling to the boom along its deployed length.

Figure 5: Topaz II Reactor Subsystem Integrated with the Separation Boom.

Topaz II Reactor Subsystem Development and Testing

The Russian Topaz II development and test program ran from 1969 to 1989. The following is a brief summary of the Russian system tests and the designators used for naming the systems.

The Russians used three designators to name their systems based upon predicted and as-built quality of the system: Eh, Ya, and V. An "Eh" system was intended to be a flight system. It could also be used for any of the other four types of systems testing depending upon why the system was fabricated and the as-built quality of the system. A "Ya" system could not be used for flight, but could be used for all other four types of systems testing. A "V" system was fabricated for either thermophysical or mechanical systems testing. A fourth type of system was the static mockup (SM), which was comprised of the three primary load bearing structures: the reactor, the shield, and the frame. The SM was used as part of the mechanical systems acceptance testing by statically loading the system structure[3].

The Russian Topaz II systems testing program collected data on systems operation, nuclear characteristics, startup characteristics, unit strength under mechanical loads, temperature profiles under launch environments, and many other critical parameters necessary to prove to the military customer that the Topaz II system would meet the power and lifetime requirements. In general, the systems were tested under prototypic conditions[3].

The Russian Topaz II systems test program was organized into four major categories: thermophysical testing using electric heaters; mechanical testing, which included static load testing, dynamic testing, and impact/shock testing; nuclear ground testing; and cold temperature testing (CTT) to simulate prelaunch and launch temperature conditions. Twelve thermophysical tests, four dynamic tests, four static tests, two shock and vibration tests, ten zero power tests, six nuclear ground tests, and four CTTs were performed.

Thermophysical Testing: Thermophysical testing was completed as part of the process of filling the systems with gases and fluid, and as part of the system acceptance testing. The U.S. TSET facility in Albuquerque is also equipped with a complete test stand where they are performing thermophysical testing of the Topaz II units.

Mechanical Testing: The primary purpose of the mechanical tests was to verify the system's strength and operability during launch and after separation through the application of mechanical loads on the system. Mechanical testing was sub-divided into three major categories: vibration testing, static load testing, and impact/shock testing. The vibration testing was done to simulate transportation and launch-induced vibrations. Static tests were performed for adequacy of structural integrity by applying concentrated loads to the primary load bearing structures. The impact/shock tests were done to simulate the separation phase of the launch vehicle from the satellite. The Topaz II systems did not undergo acoustic testing in Russia, but it is being considered by the U.S. test program.

Nuclear Ground Tests: The purpose of the nuclear ground tests was to verify the nuclear performance and control parameters of the reactor, and to verify long-term operation of the

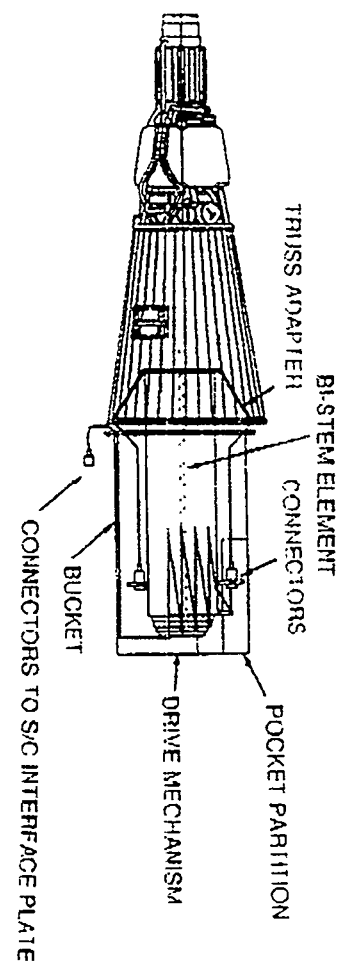

TRUSS ADAPTER
BI-STEM ELEMENT
CONNECTORS
POCKET PARTITION
DRIVE MECHANISM
BUCKET
CONNECTORS TO S/C INTERFACE PLATE

Figure 5

system in a radiation environment. Two test stands were used for nuclear testing: the Romashka, located at KIAE in Moscow, and the Turaevo test stand at the Scientific Institute for Instrument Building of the Ministry of Atomic Energy, outside Moscow. A total of six nuclear power tests were completed.

Cold Temperature Testing (CTT): CTT was done to ensure that there was adequate heat storage capacity in the reactor subsystem after pre-launch heating to keep the NaK coolant from freezing during the pre-launch, launch, and orbital ascent operations. The NaK coolant freezes between -5 to -11°C depending upon the off-eutectic sodium-potassium composition. Pre-launch simulation was performed at CDBMB where the reactor could be heated and allowed to cool. The systems were then transported to thermal vacuum facilities at the Research Institute of Chemical Machine Building in Zagorsk where the launch simulation was accomplished. Four systems underwent CTT: V-13, V-15, V-71 and Eh-40.

Topaz II Reactor Subsystem Issues and Modifications

To ensure the Topaz II could be launched by the U.S. integrated with a U.S. spacecraft, the following five modifications were initially studied for the TOPAZ II system[5]:

* Automatic Control System (ACS)
* Anti-Criticality Device (ACD)
* Reactor Fuel
* Thermal Cover
* Reentry Shield

(Also being considered for modification are the TOPAZ II load bearing frame and the radiator.)

The modification were being designed, reviewed, tested and qualified for the predicted operational conditions subsequent to the "proof-of-principle" during prototype design and testing. In general, the Military Handbook (DOD-HDBK-343 USAF), "Design, Construction, and Testing Requirements for One of a Kind Space Equipment" is being used as a guideline for the design, construction, and testing of the proposed modifications. The program sponsor at DOD HQ has determined that TOPAZ II has a "Class B" classification as defined within DOD-HDBK-343.

The following is a brief description of each of the proposed modifications:

ACS: The original Russian TOPAZ II ACS design and construction was based upon electrical devices and logic developed in the early 1970s. Therefore, the TOPAZ II team decided to develop the ACS based upon the U.S. electronics technology using the developed and tested Russian reactor control logic.
Anticriticality Device: A concept of launching the reactor with some of the fuel located outside of the reactor TFEs was selected to ensure that under any postulated accident conditions the reactor would not go critical. This included assuming that all interstitials within the core were flooded with water and the outside of the core was surrounded by either water or wet sand.
Reactor Fuel: The TOPAZ II reactor uses 96% enriched UO2 fuel which has been under development by the Russians for a many years. The Topaz team has been evaluating either purchasing the fuel from the Russians or fabricating it within the U.S.
Thermal Cover: The TOPAZ II system requires that the reactor system be heated on the pad prior to launch to ensure that the NaK does not freeze. A thermal cover is required for the TOPAZ II to ensure that the NaK coolant remains above its freezing temperature.
Reentry Shield: The issue of whether or not a reentry shield is required for the U.S. launch of a TOPAZ II system was carefully discussed by the NEPSTP Safety Team and it was concluded that a reentry shield was not required.

The modifications required for the U.S. launch of a TOPAZ II are relatively minor. The modifications are required because of different safety and launch requirements in the U.S. as compared to Russia. Studies have shown that the TOPAZ II system is adaptable to the above modifications.

Conclusion

The NEPSTP program was successful in the design of a spacecraft and mission that could use the existing Russian Topaz II space reactor system with minor modifications. The U.S. has indefinitely delayed the execution of the NEPSTP mission due to changes within the organizational mission of the SDIO, renamed the BMDO. The interaction between the Russian Topaz II spacecraft and reactor subsystem designers has been especially rewarding and a model for the two countries in a focused and cooperative effort.

Acknowledgments

This work was funded by the Ballistic Missile Defense Organization under the Department of Defense. One author is employed by Los Alamos National Laboratory, which is operated by the University of California for the U.S. Department of Energy. The other author is employed by the Applied Physics Laboratory, which is operated by the John Hopkins University. The authors would like to express their appreciation to the many Russian specialists that have made working on the Topaz II a true adventure.

References

1. Topaz II Design Evolution, S. Voss, 11th Symposium on Space Nuclear Power, Albuquerque, NM, January 1994 (LA-UR-93-3778).

2. Integrated Safety program for the Nuclear Electric Propulsion Space Test Program, A. Marshall et al., 11th Symposium on Space Nuclear Power, Albuquerque, NM, January 1994.

3. Russian Topaz II System Test Program (1970-1989), S. Voss and E. Rodriguez. 11th Symposium on Space Nuclear Power, Albuquerque, NM, January 1994 (LA-UR-93-3398).

4. Topaz II Description and Overview, S. Voss, Space 94 - The 4th International Conference and Exposition on Engineering, Construction, and Operations in Space, February 26- March 3, 1994. Albuquerque, NM (LA-UR-94-4).

5. Topaz II Reactor Modifications Overview, R. Haarman, S. Voss and V. Usov (KIAE). 11th Symposium on Space Nuclear Power, Albuquerque, NM, January 1994 (LA-UR-93-3393).

6. Utilizing a Russian Nuclear Reactor for a United States Space Mission: Systems Integration Issues, E. Reynolds, E, Schaefer, G. Polansky, J. Lacy, and A. Bocharov, 11th Symposium on Space Nuclear Power, Albuquerque, NM, January 1994.