TOPAZ II REACTOR MODIFICATIONS OVERVIEW

Roy A. Haarman and Susan S. Voss
Los Alamos National Laboratory
Los Alamos, NM 87544
(505) 665-5520

Veniamin Usov
Kurchatov Institute of Atomic Energy
Moscow, Russia
196-7111

Abstract

A proposed launch of the Russian TOPAZ II power system by the United States will require compliance with U.S. environmental, safety and health (ES&H) regulations. Recent work done by the TOPAZ II Flight Safety team in assuring ES&H compliance for a proposed TOPAZ II flight program has identified some modifications that are necessary to meet United States (U.S.) requirements. There are also some components, particularly in the electronic control area, where more modern components can improve the operability and reliability of the mission. This paper describes the overall approach to considering modifications on the existing TOPAZ II system from both the ES&H and operational aspects, and provides a brief description of each of the proposed modifications.

BACKGROUND

The U.S. TOPAZ II Safety Team, under the Nuclear Electric Propulsion Space Test Program (NEPSTP), began work in mid-1992 to investigate safety issues relative to the proposed flight of a TOPAZ II reactor in early 1995. Their initial charter was to identify "show-stoppers" that might prevent launching of the TOPAZ II by the U.S. Technical experts from a number of scientific organizations were involved in this assessment and although no "show-stoppers" were identified, it was determined that a few changes were necessary to meet both the unique launch characteristics from a launch at Kennedy Space Center and safety requirements imposed by the U.S. team. These changes were assigned to the TOPAZ II Modifications Team, consisting of both U.S. and Russian engineers whose function is to develop criteria, conceptual designs, test plans, and final designs for the proposed modifications.

Concurrent with the safety assessments, testing was done at the Thermionic System Evaluation Test (TSET) facility in Albuquerque, NM and systems analyses were performed by U.S. and Russian specialists. As a result of the testing and the analysis, there were a number of proposed changes to components and/or subsystems that could improve the TOPAZ II system reliability. After these changes were identified, the task of implementing the modifications was assigned to the Modifications Team within the NEPSTP program.

Currently, all significant modifications have been identified, but as NEPSTP continues to assess the TOPAZ II system for integration with a U.S. spacecraft and launch vehicle, as the U.S. knowledge of the TOPAZ II system and components increases, and as we obtain further results from the TSET tests, other modifications may be identified.

MODIFICATIONS

Close coordination between the U.S. and Russian engineers is crucial for success in developing modifications to the Russian TOPAZ II system. The U.S. NEPSTP program participants have had to be cautious to ensure that they adhere to the U.S. National Disclosure Policy and do not discuss specific U.S. technologies with the Russian specialists. A request has been sent for exemption of certain items specific to the TOPAZ II project, but until an exemption is granted, participants must carefully restrict their discussions.

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 general process for developing the modifications is similar for all modifications. The original need and criteria for a modification is developed by the NEPSTP team that is responsible for safety or operation. In most instances, fairly extensive review or analyses are necessary to identify the need and to define the criteria. Each subteam presents the issues to a group of engineers and scientists to debate the need and criteria for the modification. For safety issues, the modifications are also presented to safety working groups for discussion and resolution. The issues are also discussed with the Russian participants in both Russia and the U.S. to gain as wide an audience of knowledgeable experts as possible.

Once a modification is determined to be required, the modifications team, using the criteria developed by the safety or operations team, initiates the work on several conceptual designs. A single concept is then chosen by weighing safety, reliability, operability, and manufacturability. The work continues then on a single concept to the preliminary design phase. The design is presented at a Preliminary Design Review (PDR) for comments and recommendations by an independent review panel, prior to going into the detailed design phase and the manufacturing and testing of the prototypes. Not all of the proposed modifications have evolved to the prototype design stage. In fact, the Reentry Shield was determined to not be required and therefore never entered the detailed design stage. Further information will be presented on the Reentry Shield later in this report.

The following are the five modifications that were initially identified for the TOPAZ II system:

- Automatic Control System
- Anti-Criticality Device
- Reactor Fuel
- Thermal Cover
- Reentry Shield

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

The modification is designed, reviewed, tested and qualified for the predicted operational conditions subsequent to the "proof-of-principle" during prototype design and testing. Installation and testing as part of the flight TOPAZ II unit is a function of system integration issues that will not be covered in this paper.

Automatic Control System

The Automatic Control System (ACS) is a closed loop feedback system that controls the reactor system during startup and normal operation. It consists of two parts: the reactor control unit (RCU) and the power supply system (PSS). The ACS receives signals from sensors throughout the system (thermocouples, flux detectors, etc.), calculates the necessary control functions to maintain the reactor system within specified limits of power, temperature, and output voltage, and sends signals to the reactor control elements to keep the system within its operational limits.

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. The RCU is being developed by NMERI, and the PSS is being developed by the Applied Physic Laboratory (APL) in Baltimore, MD. This decision has also helped to simplify the integration of the ACS with the U.S. designed spacecraft module and the launch vehicle command system.

The Russians proposed a new "turn-key" ACS system that would meet the modern requirements and the U.S. ACS team is evaluating the Russian proposal. In the interim, the U.S. is working on a parallel system that will be integrated with the U.S. spacecraft.

Anti-Criticality Device

In the Fall of 1992, the TOPAZ II reactor was modeled by the U.S. using the LANL MCNP code and the resulting neutronics analysis indicated the possibility that the reactor could go critical if immersed in water and surrounded by wet sand following a launch abort. The scenario leading to such a condition had a greater probability of occurrence from a U.S. launch site than from a Russian launch site because of the trajectory of the U.S. launch vehicle over water.

The specific scenario of concern is an aborted launch that does not achieve orbit leading to the reentry of the nuclear reactor into water, and the additional possibility of surrounding the reactor with wet sand. This scenario was considered for two cases: with the external reflectors on and without the external reflectors in place. The U.S. team is assuming the worse case conditions of for water ingress into the core by assuming that water fills all potential cavities within the reactor, including the coolant region. Although the probability of such an occurrence is admittedly low, the U.S. safety team believes that such an accident involving a possible criticality excursion would not be acceptable.

The U.S. and Russian engineers developed a number of possible modifications which would prevent water criticality. These were thoroughly analyzed and reviewed, but the most acceptable designs revolved around two basic concepts - the "fuel-out" concept and the "poison-in" concept. These concepts are easily integrated with the TOPAZ II system because it is designed with the fuel rods which can be opened at the end of the TFE for fuel loading after completion of system assembly.

The concept chosen for further development was the "fuel-out" option, it consists of launching the reactor with a specific amount of the nuclear fuel removed from the core region until a safe orbit has been achieved. Once the orbit has been verified through the network of ground stations, the remaining fuel would be inserted into the reactor core and the startup begun. The advantage of the fuel-out concept is that under all accident conditions the anticriticality device would either remain in place or remove the fuel away from the reactor and therefore to a safer configuration. The "poison-in" concept is characterized by launching the reactor with poison inserted within selected TFEs in the fueled zone which could then be withdrawn after safe orbit is achieved. Both concepts are practical, but the fuel-out concept was selected because of its inherent fail safe characteristic. Details of this design are being presented in another paper at the symposium.

Reactor Fuel

The TOPAZ II reactor uses 96% enriched UO_2 fuel which has been under development by the Russians for a many years. The close tolerances required in thermionic reactors between the emitter and collector gap dictate a high mechanical strength of the TFE and limited fuel swelling. The Russians have developed an extensive database on UO_2 fuel that can withstand the launch environment, operate at elevated temperatures, and have stated improvements of a factor of two in minimizing of fuel swelling. The Russian TOPAZ II has increased their operating lifetime by increasing the number of thermionic fuel elements from 31 to 37, and by optimizing the fuel inner to outer diameter as a function of position within the core. In addition, the importance of high strength fuel is required to ensure that the fuel can withstand the vibration loading induced during the launch and separation phases of the mission. Technology in this area is of interest to the U.S. and joint work between the fuel experts at Los Alamos and the Russians has been ongoing.

A major decision faced by the TOPAZ II program is whether to produce the fuel in the U.S. or purchase it from the Russians. Both options are being pursued because acquisition of the Russian fuel may prove to be very difficult. The Russians indicate they have the equivalent of two full core loads already produced which have been qualified for a flight demonstration. NEPSTP has been working over the past year to try and arrive at a joint U.S./Russian process by which the U.S. could purchase the existing Russian fuel. It is of primary concern that the process would provide high assurance to the U.S. that the fuel meets the technical specifications and performance as described by the Russians. In addition, the U.S. has also been developing the process to make the fuel in the U.S. should it prove as an alternative to purchasing it from the Russians. U.S. fuel specialists have been working closely with the Russians to understand the mechanical and chemical properties of the fuel.

Knowledge of the physical properties of the fuel together with fuel handling techniques associated with fuel loading are particularly important in the design of a fuel-out anti-criticality device. Mechanical engineers in the U.S. and Russia are working together to exchange ideas and experience on these fuel loading issues.

The DOD has been working with the DOE, who has the national responsibility for special nuclear material issues, to arrive at a mutually agreeable solution to acquire, safeguard, and transport the TOPAZ II fuel from Russia to the U.S. An exemption (a 91b) was granted to the DOD by DOE for purchase of two TOPAZ II reactors without fuel, for testing at TSET. The exemption is required for DOD to take ownership for the reactor units without fuel because they are classified as nuclear devices. The DOE has not yet decided whether or not to agree on the purchase of the Russian fuel, and which government agency will have prime responsibility if it is purchased (either DOE or DOD).

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 of -11 to -5 C prior to launch or during the launch phase prior to reactor startup. The thermal cover reduces heat loss from the system. The design of the thermal cover is important to mission success, because if the NaK freezes in orbit prior to reactor startup and operation it may not be possible to operate the reactor.

The thermal cover incorporates both passive thermal protection and an active ejection device which must release and push the thermal cover away from the satellite after during the reactor startup. The Russians had two designs for the thermal covers: one for an upright launch and one for an inverted launch. The Russians currently have thermal covers available for an inverted launch. Therefore, since the U.S. is planning on launching the system in an upright configuration, an existing, off-the-shelf thermal cover is not available.

The U.S. is planning on modifying the TOPAZ II system to incorporate the anticriticality device on the top of the reactor vessel, this would require changes to either of the Russian designed thermal covers. Also, the U.S. prelaunch and launch conditions are under less severe environmental conditions than the conditions for which the Russians designed their thermal cover for, and therefore a less robust thermal cover may be acceptable. The U.S. will continue to work closely with the Russian team in the design, analysis and testing of the modified thermal cover.

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. Concern revolved around the potential breakup of the core if the reactor reentered prior to achieving the designated orbit. This scenario examined reentry during the orbital ascent phase and the possibility of achieving a low-lived orbit in which operation would be restricted. Once in the high orbit required for operation, the reactor would not reenter for hundreds to millions of years.

Given reentry at the early stages of the flight, the reactor fuel would be unirradiated and not a health concern. Calculations for an uncontrolled reentry showed there would be some burnup of the reactor but the UO_2 fuel pellets would remain essentially intact. The issue of safeguards was debated and the tradeoff between keeping the core intact with the special nuclear material in a single retrievable point versus scattering the material in an uncontrolled manner over a large area was discussed. It was decided that from a safeguards perspective it was better to allow the unirradiated fuel to be scattered over a large area. Based on these considerations it was concluded that a reentry shield was not required.

SUMMARY

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 modifications. Flight of the TOPAZ II remains a good opportunity to demonstrate the usefulness of a nuclear reactor power source in space as long as the program can continue to meet the U.S. safety requirements and performance requirements with a minimum number of modifications. Work will continue on providing further definition, design, testing, and integration of the ACS, the anticriticality device, the reactor fuel, and the thermal cover.

Additional value in this program is the integration of U.S. and Russian engineering design and test approaches towards a single, common objective. It is obvious that the fundamental approaches used in the two countries relative to engineering and applied sciences can work together and gain from each other.

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Reference

USAF Military Handbook (DOD-HDBK-343 USAF) "Design, Construction, and Testing Requirements for One of a Kind Space Equipment."