**T515 NASA Nuclear Canister for Space**

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**After almost a 60-year break, NASA has decided to refocus their attempts on using nuclear thermal propulsion (NTP) as a more efficient way to advance space exploration. The NTP process uses uranium to heat hydrogen to create thrust. This process is more efficient than conventional rocket engines. NASA’s research has restarted with the Transient Reactor Test Facility (TREAT). The TREAT reactor is used to test different fuels for NTP. The TREAT reactor can rapidly heat the fuel to test NTP engine startup. The objective is to design, build, and test a canister for the TREAT reactor. The canister is inside the SIRIUS (an acronym with no meaning) module. The SIRIUS module will provide the hydrogen to the canister. The SIRIUS module will be inside Big BUSTER (Broad Use Specimen Transient Experiment Rig), which goes into the TREAT reactor. The canister holds uranium in the center of the canister that will heat the hydrogen flow to test the different fuels.**

**The design choices were based around the fuel and hydrogen in the canister. The materials used for the canister is tungsten and zirconium carbide to ensure it will not fail at high temperatures. The tungsten can withstand the high temperatures and the zirconium carbide keeps the hydrogen from sticking to the canister. There are multiple small flow channels that allow for a high and constant flow rate of hydrogen through the canister.**

**To test the canister, a heating device is placed inside our experimental canister. This allows for a small-scale simulation of a nuclear heating without using dangerous and unobtainable materials. Argon will function as liquid hydrogen due to its ease of use and availability. Thermocouples will measure the temperature difference and allow for calculations to be made to relate the results from testing to a full-scale test that will be done by NASA.**

# **I. Nomenclature**

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| NASA | = The National Aeronautics and Space Administration |
| TREAT | = Transient Reactor Test |
| INL | = Idaho National Lab |
| NTP | = Nuclear Thermal Propulsion |
| BUSTER | = Broad Use Specimen Transient Experiment Rig |
| K  | = Kelvin |

# **II. Introduction**

## **Project Description**

Our client, Marvin Barnes at NASA, needs a canister that can be incorporated in their “Big Buster” project. The Big Buster project involves NASA testing multiple types of elements as a baseline fuel for a nuclear reactor. The canister will go into the section of the Big Buster where the fission reaction occurs and produces a level of heat that is typically around half that of the sun. To achieve this, the canister needs to be made from a material that can withstand 3000 K. Within NASA’s Big Buster project, the fluid reacting to the baseline fuel is hydrogen, this indicated that the material our canister is made of cannot be able to react with hydrogen any temperatures. The Big Buster project is used for testing at the transient reactor testing facility (TREAT Facility) in Idaho Falls, Idaho.

## **Project Objective**

The objective of the project is to develop and test a canister to go into Big BUSTER and the SIRIUS module to test nuclear fuel compounds for thermal nuclear propulsion systems in the Transient Reactor (TREAT).

## **Key Goals**

The main objective of this project is to design and develop a canister that will safely contain the nuclear reaction between the baseline fuel and the fluid it reacts with. The baseline fuel will start out as uranium nitride. If successful, multiple other baseline fuels will be tested. The biggest obstacle will be the reaction temperature of a fission reaction and the lack of a reaction between the walls of the canister and the fluid.

## **Assumptions**

Most assumptions will come from the fact that the use of our canister will occur in Idaho Falls, Idaho. Another key aspect is knowing that after each use of the nuclear reactor, there is a down period of roughly three to five months of inactivity and the average temperature of a fission reaction that creates the most energy is 3,000 K and that the material needs to withstand that temperature. It is safe to assume that the weight of the canister will not affect the use or efficiency of the overall system given that the canister is for testing purposes. The Big Buster, where the canister is involved, is mounted on the ground and not for use in space, meaning weight is not a concern. Another assumption made is that the correct ratio of baseline fuel and hydrogen will be offered within the canister and that everything else in Big Buster is working according to plan. Even though nuclear reactions create a radioactive product, the assumption will be made that we do not need to have a material that absorbs radioactivity. This is due to the short run time of the testing, the five-month down period, and the precautions taken by NASA to prevent interactions with radioactive material. If the reaction was tested for a longer time, then radioactive absorptivity would be considered when selecting a material.

# **III. Targets and Metrics**

For the function of the NTP reaction process, this must first be broken down into the basic elements of a nuclear reaction. In a nuclear reaction, a neutron collides with a uranium atom, splitting it releasing energy in the form of heat and radiation. In the case of a nuclear thermal propulsion engine, making sure the neutrons are reflected is key because low enriched uranium will be used as fuel. This creates a target of less than 10% absorption for neutrons. This metric was decided due to the importance of neutrons in the reaction. The thermal energy released from the reaction will destroy the canister if not properly accounted for, leading to a target for the material to withstand 3000K. The metric for this target is temperature. The energy released in the form of radiation can change the molecular structure of the material. This leads to radiation hardening, that can cause the materials properties to be no longer mechanically sound and cause failure. This leads to a target of no greater than an 8 GPa change in hardness over the course of the test. This would be measured with a hardness test. This target will also allow for the canister to be reusable, preventing the canister from becoming too brittle to reuse. A main function of the canister is to fit within Big Buster. While the exact dimensions of the location within Big Buster is not known at the time, the initial target is presented to be 10 inches in length and 2 inches in diameter. The metric of length and diameter were chosen due to the constraints put in place during the design of Big Buster and the TREAT reactor. The uranium used within the test must fit within the canister for the research to be conducted. While the volume of the uranium is not a limiting factor, accounting for different configurations of uranium being used creates unique targets for each configuration, with the initial test using a structural matrix to hold the uranium in place. The exact volume of uranium being used is not known; however, the target can be created assuming the amount of uranium used is equivalent to the size of a marble. This is enough uranium for a one-way trip to Mars, which has a mass of 175 grams and a volume of 9.2 $cm^{3}$. The flow of hydrogen is critical to the success of the research. The flow of hydrogen provides two purposes in the canister, it adds a level of cooling to the system, due to it entering the system as a cooled liquid, and it produces a net thrust in a thermal nuclear engine. The hydrogen must be continually flowing in one direction, this leads to a target of a net pressure difference in the canister greater than zero. This metric was chosen due to a net pressure difference indicating the flow of the fluid, in this case hydrogen. To sustain the required specific impulse of 900 *seconds* for the nuclear thermal propulsion engine a mass flow rate of 13$\frac{m^{2}}{sec}$ is required for the entire engine. Big Buster will be testing the equivalent of one of six fuel rods leading to a target of 2.2 $\frac{kg}{sec}$. The metric for this target is mass flow rate. This mass flow rate of liquid hydrogen will also allow for additional cooling to the canister increasing the decreasing the effects of temperature changes. Big Buster will provide pure liquid hydrogen to the canister. If the hydrogen has the possibility to stick to the inner surfaces of the canister and create hot spots within the canister. These hot spots can superheat the hydrogen and cause diffusion of the hydrogen into the canister material and cause hydrogen embrittlement. A coating to the canister as well as flow dynamics may be used to reduce the chances of hydrogen sticking, however, the coating of the canister and the canister may have different thermal expansion rates. This creates a target for the canister and canister coating to have thermal expansion rates within $6\*10^{-6}\frac{1}{°C}$. This target will also be used when measuring the target dimensions within Big Buster. This metric is used to measure the rate at which a material expands due to the change in temperature.

# **IV. Results and Discussion**

### **Material Selection**

For the material selection of the proposed design of the canister that will be used in the TREAT Reactor, tungsten was chosen. This was chosen due to the material properties of tungsten, having a melting point of 3,693 K. This is well above the required melting point that would be experienced in the tests of 3,000 K. The canister will also be coated in zirconium carbide. Zirconium carbide also has a melting point of well above 3,000 K at 3,800 K. The zirconium carbide coating will prevent the hydrogen gas from sticking to the canister preventing hot spot propagation throughout the canister. For the experimental design of the canister, aluminum 6061 was chosen. This was due to the similar thermal conductivity properties it shares with tungsten. This allows for testing to be as close as possible to testing with tungsten and uranium.

### **Fission Product**

For the canister that will be used in the TREAT Reactor, different configurations of uranium will be used which will vary on the different fuel sources that the researched at NASA and the Idaho National Lab are testing at the time. For the experimental canister a heating element that can reach temperatures of over 100˚C­. This will allow for scaling to simulate the use of uranium at high temperatures for calculations.

### **Propellant**

For the canister that will be used in the TREAT Reactor, liquid hydrogen that will become gaseous will be used for the experiments. For testing with the experimental canister, argon will be used. Argon was chosen due to safety concerns and availability. Argon gas allowed for simpler calculations and controlled gas flow through the experimental canister.

# **V. Conclusion**

The experimental canister successfully demonstrated a temperature difference between the entrance temperature of the argon gas and the exit temperature of the argon gas when passing though the experimental canister. The temperature difference found from the experimental testing was found to be 16.1 K. Scaling these results for use in the TREAT Reactor showed that there would be a 1,200 K temperature difference when using uranium and hydrogen. This scaled value indicates a high temperature difference with the proposed design.

### **Errors**

The experimental canister had a 2.13% error from the theoretical temperature difference of 16.45 K. This difference from the experimental results and the theoretical results was from ignoring friction from the tubing and canister, from losses due to connectors connecting the various tubing to the canister and the argon tank, and from the varying ambient temperature in the lab where the experiment was conducted. To create a more accurate simulation for theoretical results, the temperature in the lab where testing is conducted should be controlled allowing for more accurate results. For calculating theoretical values, an advanced computer analysis should be conducted using exact modeled parts.

## **Future Work**

Moving forward, the creation of the proposed canister would be constructed. This along with the finalization of both Big BUSTER and the SIRIUS module, testing would then be conducted on different nuclear fuel sources. Alternate designs would be tested on a smaller scale using the experimental method would allow for different configurations to be tested and the results compared to the original experimental canister. These results would then allow for different canisters to be used for different types of experiments with nuclear fuels. Alternate designs proposed to NASA would also allow for different types of experiments to be conducted to test different propellants that could be used with NTP allowing for more efficient and powerful NTP engines to be researched and produced.

# **Concluding Remarks**

Overall, the experimental canister created a small-scale representation of the canister that will be used for research into NTP that will be conducted by NASA and the Idaho National Lab. The material selection for the proposed canister would meet the requirements for full scale nuclear fuel experimentation using the TREAT Reactor. The research that will be conducted from the canister would allow for improved nuclear fuels to be researched allowing for more efficient and powerful NTP engines. The finalization of Big BUSTER and the SIRIUS module may change the final dimensions of the canister, however based on the material provided, the canister meets the requirements set by NASA.

**VI. Acknowledgments**

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The designed canister was not able to be machined using conventional techniques due to its long length and small diameter holes. The canister’s room for error was also extremely small to obtain reasonable results. Due to these concerns, Lundy Enterprise was chosen to gun barrel drill the canister. Lundy Enterprise was able to supply a fantastically machined canister with a tolerance low enough to confidently perform the experiments.

Lastly, Dr. Shayne McConomy assisted the team in the correct direction of the project by offering advice and networking to help the team when at crossroads. At times of confusion and concern, Dr. McConomy was available and willing to use his experience as an expert and professor to aid the team.