A RESEARCH REACTOR CONCEPT TO SUPPORT NTP DEVELOPMENT M.J. Eades[1], T. E. Blue[1], H. P. Gerrish[2], L.A. Hardin[3], [1]The Ohio State University, 201 W. 19th Avenue, Columbus, OH, 35812, USA (email: eades.15@osu.edu), [2]National Aeronautics and Space Administration, MSFC-ER20, MSFC, AL 35812, USA (email: harold.p.gerrish@nasa.gov), [3]U.S. Nuclear Regulatory Commission, RES/DE/ICEEB MS: CSB-02A07M, Washington, DC 20555-0001, USA (e-mail: leroy.hardin@nrc.gov)

Introduction: In support of efforts for research into the design and development of man rated Nuclear Thermal Propulsion (NTP), the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), is evaluating the potential for building a Nuclear Regulatory Commission (NRC) licensed NTP based research reactor (NTPRR). The proposed NTPRR would be licensed by NASA and operated jointly by NASA and university partners. The purpose of the NTPRR would be used to perform further research into the technologies and systems needed for a successful NTP project and promote nuclear training and education.

Purpose: A successful NTP system is vital to NASA's ability to safely accomplish a manned Mars mission in the 2030s timeframe. In addition, many other space missions would benefit greatly from NTP capabilities. The proposed research reactor would support research, testing and training related to NASA's NTP efforts.

An NRC regulated research reactor is a particularly appealing milestone for Low Enriched Uranium (LEU) NTP development [1]. LEU NTP will have less regulatory burden during testing and have more development options compared to NTP concepts that use Highly Enriched Uranium (HEU). An NRC regulated NTP research reactor capitalizes on the development options enabled by LEU by offering an achievable milestone between zero power critical and full power test. A 10 MW or less NTPRR would allow for more extensive testing and characterization beyond what is possible with a zero power critical, but would likely require less regulatory input than a full power NTP test.

Specifically, the proposed reactor would assist in NASA's NTP development in five key ways:

1. An NTPRR is a relatively low cost but important step towards a full scale NTP test. Designing, building and managing a research reactor similar to an NTP reactor would inevitably result in lessons learned and invaluable technical and regulatory experience that would aid in NTP development.

2. A NASA research reactor supporting NTP development would help familiarize the personnel and management with nuclear systems. This could possibly streamline future NTP ground testing and reduce risk in schedule.

3. The proposed NTPRR would be able to demonstrate the integrity of NTP fuel and the retention of fission products in a characteristic nuclear, thermal and corrosive environment.

4. A man rated NTP reactor requires more extensive data on radiation damage effects on materials than is available in the current literature. The potential research reactor could provide the facilities needed to generate radiation damage data. Furthermore the radiation environment provided by the proposed research reactor would likely be more similar to the NTP radiation environment than the radiation environment provided by common light water research reactors.

5. The NTPRR would have a similar neutronic environment to a low enriched uranium tungsten cermet NTP reactor and would be a good benchmark for codes modeling a full scale NTP. This bench marking would decrease uncertainty in the design of a full scale NTP test.

Proposed Design: The final design of the NTPRR will be driven by down selects made during NTP development, but the NTPRR will also be flexible enough to test a number of NTP technologies. Currently envisioned is a reactor based loosely on the LEU W-UO_2 cermet fuel $ZrH_{1.8}$ moderated NTP concept presented in [1]. The NTPRR will be capable of supporting a number of different hexagonal prism fuel and tie tube configurations. Fuel options include NTP fuels, such as W-UO_2 cermet and graphite composite fuels, and more traditional research reactor fuels, such as U_3Si_2. Using a traditional research reactor fuel will allow: 1) the NTPRR to be certified and start operation, before the NTP fuel is fully qualified for operation, 2) irradiation of single NTP fuel elements, and 3) operation of the NTPRR as a research reactor for non NTP related purposes.

Configurations of the NTPRR with sustained operation above 10 MW could potentially allow for prototypic power densities in the NTP fuel to be achieved; although operation above 10 MW would put the NTPRR into the NRC's test reactor category and would require additional regulations to be fulfilled.

The NTPRR will operate from room temperatures to prototypic NTP temperatures. Cooling will be provided by hydrogen or helium flowing through small axial coolant channels in the moderator and fuel. Gas will be driven by either an electrically driven compressor or a turbine and compressor utilizing NTPRR heat energy for code benchmarking purposes.

Other variations being considered include dual reactor cores operated from a single control room. This would allow for both short term operational use as well as extended duration operations simultaneously. Flux traps, neutron beams and other science facilities would also be incorporated for academic research.

Spinoff Applications: If built, the NTPRR would be a unique research asset that offers capabilities not currently available in the United States. Specifically, the NTPRR's epithermal to fast neutron flux and very high temperature operation can greatly assist in some non-NTP related experiments. Possible non-NTP applications of a NTPRR include: material damage studies, unique isotope production, and calibration of unique detectors. The specialty medical isotopes ^{32}P, ^{33}P, ^{57}Co, ^{64}Cu, ^{67}Cu, and ^{89}Sr can be produced in a fast neutron flux like that provided by the NTPRR. It is possible that these spin off applications can interest other stake holders to assume some of the cost of building the NTPRR.

In the NERVA program it was found that the zero power critical reactors that were developed to benchmark NTP neutronic calculations were also effective at driving specialty experiments that required an epithermal neutron flux [2].

MCNP6 calculations have been conducted on a preliminary concept of a research optimized NTPRR. Figure 1 presents the energy distribution of the neutron flux of the NTPRR, HFIR PTP and Watt fission spectrum presented as a complementary cumulative distribution function for the flux in the Central Irradiation Facility (CIF) of the NTPRR and compares it to the Watt fission spectrum and the Peripheral Target Position in the High Flux Isotope Reactor (HFIR PTP). The HFIRPTP is a location often used when a high energy flux is desired. The MCNP6 calculations predict a much harder energy distribution for the flux in the NTPRR's CIF than in the PTP HFIR. At 10 MW, the total calculated flux for the NTPRR's CIF is 3.3×10^{14} and it is predicted to be able to produce 4.2 dpa in SiC per EFPY.

Planned Schedule: NASA began engaging the NRC in preapplication discussions regarding this concept in the 4th Quarter of FY 13. The purpose of this and future discussions will be to identify any special areas of concern and to support the development of a quality application to support an efficient, effective and timely review by the NRC. The design and licensing of any additional facilities to support the operation of this reactor (to include hotcells for system evaluation) would be included in this application. Any required support for transportation of fresh or used fuel (to include reactor component assemblies) would be addressed through interaction with and application to the NRC's Office of Nuclear Material Safety and Safeguards (NMSS).

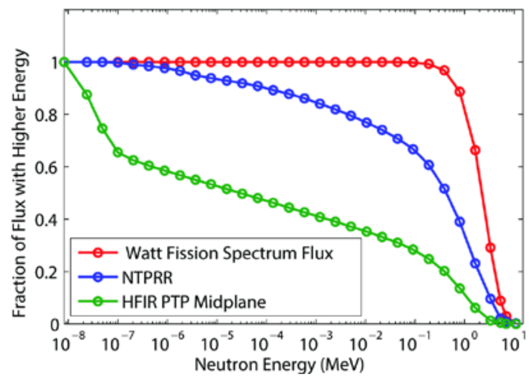

Figure 1:The energy distribution of the neutron flux of the NTPRR, HFIR PTP and Watt fission spectrum presented as a complementary cumulative distribution function.

Conclusion: The proposed NTPRR would provide a valuable asset to NASA's effort to develop and fly an NTP for manned Martian exploration. In addition, this reactor would provide an invaluable research asset to affiliated universities.

References: 1. Venneri P., Deason W., et. al. (2014) *Nuclear and Emerging Technology for Space* .2. Paxton H. C. (1983) *Los Alamos National Laboratory* LA-9685-H. Some text taken from Eades M. Gerrish H. P. et. al. (2013) *ANS Winter Meeting* Vol. 109 N. 1 P. 42-43

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