Current Ground Test Options for Nuclear Thermal Propulsion (NTP). H. P. Gerrish Jr, NASA Marshall Space Flight Center, ER20, Huntsville, AL 35812, harold.p.gerrish@nasa.gov

Abstract: About 20 different NTP engines/reactors were tested from 1959 to 1972 as part of the Rover and Nuclear Engine for Rocket Vehicle Application (NERVA) program. Most were tested in open air at test cell A or test cell C, at the Nevada Test Site (NTS). Even after serious engine breakdowns of the reactor (e.g., Phoebus 1A), the test cells were cleaned up for other engine tests. The engine test stand (ETS) was made for high altitude (~1 psia) testing of an NTP engine with a flight configuration, but still had the exhaust released to open air. The Rover/NERVA program became aware of new environmental regulations which would prohibit the release of any significant quantity of radioactive particulates and noble gases into the open air. The nuclear furnace (NF-1) was the last reactor tested before the program was cancelled in 1973, but successfully demonstrated a scrubber concept on how to filter the NTP exhaust.

The NF-1 was demonstrated in the summer of 1972. The NF-1 used a 44MW reactor and operated each run for ~90 minutes. The system cooled the hot hydrogen exhaust from the engine with a water spray before entering a particle filter. The exhaust then passed through a series of heat exchangers and water separators to help remove water from the exhaust and further reduce the exhaust temperatures. The exhaust was next prepared for the charcoal trap by passing through a dryer and effluent cooler to bring exhaust temperatures close to liquid nitrogen. At those low temperatures, most of the noble gases (e.g., Xe and Kr made from fission products) get captured in the charcoal trap. The filtered hydrogen is finally passed through a flare stack and released to the air. The concept was overall successful but did show a La plating on some surfaces and had multiple recommendations for improvement.

The most recent detailed study on the NTP scrubber concept was performed by the ARES Corporation in 2006. The concept is based on a 50,000 lbf thrust engine (~1 GW) with a maximum burn time of 1 hour. The concept utilized lessons learned from NF-1. The strategy breaks down the exhaust into parallel paths to allow flexibility with engine size and mass flow of exhaust. Similar to NF-1, the exhaust is slowed down, cooled, filtered of particulates, filtered of noble gases, and then the clean hydrogen is flared to open air.

Another concept proposed by Steve Howe (currently Director of the Center for Space Nuclear Research) to simplify the NTP exhaust filtering is to run the hydrogen exhaust into boreholes underground to filter the exhaust. The two borehole site locations proposed are at the NTS and at the Idaho National Laboratory (INL). At NTS, the boreholes are 8’ diameter and 1200’ deep. The permeability of hydrogen through the soil and its buoyancy will allow it to rise up through the soil and allow the filtering of noble gases and radioactive particulates. The exhaust needs to be cooled to 600C before entering the borehole to avoid soil glazing. Preliminary analysis shows a small buildup of back pressure with time which depends on permeability. Noble gases entering the borehole walls deep can take a long time before reaching the surface. Other factors affecting permeability include borehole pressure, water saturation, and turbulence. Also, a possible need to pump out contaminated water collected at the bottom of the borehole. At INL, the borehole concept is slightly different. The underground borehole has openings to the soil at special depths which have impermeable interbeds above the water table and below the surface to allow the exhaust to travel horizontal between the impermeable layers. Preliminary results indicate better permeability than at NTS.

The last option is total containment of the exhaust during the test run. The concept involves slowing down the flow to subsonic in a water cooled diffuser. The hydrogen is burned off in an oxygen rich afterburner with the only products being steam, oxygen, and some noble gases. A heat exchanger and water spray pulls heat from the steam and lowers the temperature for condensation. The optimum ratio between the two is being investigated, with a goal to minimize the total volume of the water hold tanks. A water tank farm collects the contaminated water. The amount of water produced from burning the hydrogen is ~100,000 gallons (not including cooling water) for a 25k lbf engine operating for 50 minutes. Residual gases (e.g., oxygen and some noble gases) can be captured at cryogenic levels with a liquid nitrogen cooled dewar. After a few weeks post-test, the radiation levels can drop to more favorable levels before slowly draining each capture tank and using existing filters.

With today’s environmental regulations, the NTP exhaust is filtered to meet 10 mrem/year exposure to the general public (at a DOE site) or 100 mrem/year (via NRC when tested elsewhere), when natural background radiation exposure to the general public is 300-600 mrem per year. The current society feels more comfortable with filtering even lower to as low as reasonably achievable (ALARA).