INTRODUCTION

Current space program plans indicate a nuclear vehicle will be developed for operation as a cargo/personnel shuttle between earth orbit and lunar orbit, between low earth orbit and synchronous orbit, and possibly for use with interplanetary probes. The economic feasibility of such a nuclear shuttle is expected to be highly dependent upon the success of propellant transfer and long-term storage in the earth orbital environment.

A propellant depot in earth orbit which is resupplied by a space shuttle, such as that shown in Fig. 1, will provide considerable flexibility in scheduling nuclear shuttle missions. Operating in conjunction with such a propellant depot, the nuclear shuttle can refuel and take on the necessary cargo and personnel within hours instead of days. Without the depot, multiple space shuttle flights—as many as twelve to

Fig. 1. Two-stage space shuttle.

sixteen per nuclear lunar shuttle mission—would be needed to refuel each waiting nuclear shuttle. The depot could also act as an orbiting resupply station (with both hydrogen and oxygen) available to other vehicles operating in its vicinity—including possibly a space station, a space tug, and both interplanetary and interstellar probes.

Slush hydrogen offers several advantages over other fuels as a nuclear stage propellant. Hydrogen has a very high specific impulse and because of the increased density of the slush, the density impulse of slush hydrogen (impulse per given volume) is higher than for liquid or gaseous hydrogen. Because of the absence of the normally low-specific-impulse gelling agent, it is also higher than the specific impulse for gelled hydrogens available today. Slush hydrogen will absorb more heat than liquid or gaseous hydrogen for a given increase in pressure due to the energy absorbed from heat of fusion of the solid hydrogen in the slush.

**LAUNCH PAD OPERATIONS**

Slush hydrogen must be generated, stored, and transferred to the space shuttle at the launch pad. To date four methods have been evaluated for producing the slush: helium refrigeration, helium bubbling, continuous vacuum bubbling, and intermittent vacuum pumping (freeze–thaw process). Of these four, the freeze–thaw process has appeared most promising. A 35% solid fraction (slush quality) is normally achieved from the freeze–thaw process. A 60% solid fraction may be achieved through slush topping and liquid draining with a two-day aging period to allow the slush solids to break into finer particles and settle to the bottom of the storage dewar. After the slush is generated, it must either be stored or transferred directly to the space shuttle. Two methods available for transfer are by (1) pressure and (2) pump. Experiments have been successful in transferring slush by both methods with equipment designed for liquid hydrogen.

Current space shuttle concepts have considered total discretionary cargo capacities of up to approximately 50,000 lb. For the propellant tanker design concepts, the estimated amount of liquid hydrogen deliverable per trip is about 41,000 lb. Slush generation and transfer equipment must be capable of rapidly filling the shuttle slush cargo tanks. The optimum slush qualities must be determined for the various phases of the orbital propellant depot mission from generation at the pad through transfer to the nuclear shuttle. Launch pad slush hydrogen facilities must be designed to generate and transfer slush of quality and quantity consistent with optimum mission performance.

**SPACE SHUTTLE INTERNAL SLUSH FACILITIES**

Slush storage tankage in the space shuttle cargo bay will receive the slush hydrogen from the transfer lines at the launch pad. The slush must be stored in the shuttle under multiple environmental conditions: (1) prelaunch—ambient temperature and pressure, little vibration, 1 g gravity; (2) launch—increasing and later decreasing temperatures, decreasing pressures, vibration, increasing and later decreasing gravity; and (3) orbital rendezvous—orbital temperatures, low pressure, little vibration, near-neutral gravity. The multiple environmental conditions dictate strenuous requirements for the slush thermal protection system.

Preliminary investigations indicate that a 50% slush mixture contained in the shuttle tankage insulated by a 1-in.-thick internal conventional foam insulation will melt completely within approximately 6 hr after completion of topping operations (under conditions of launch and initial orbital environment). Therefore, to minimize