Establishing Operational Altitudes for Nuclear Thermal Propulsion in Earth-Orbit

BUSINESS PROBLEM

Nuclear Thermal Propulsion (NTP) is a leading candidate for high-energy cislunar and deep-space missions because it can significantly improve mission performance compared with chemical propulsion. Emerging mission architectures require assembling the propulsion system and propellant tanks in Earth orbit before departure. Operational altitude during this phase affects regulatory approval, public risk, mission risk, and launch cost. No clear framework exists to determine acceptable orbital altitudes for commercial NTP systems under the modern U.S. regulatory environment, creating uncertainty for operators planning nuclear-enabled missions.

DATA SOURCES

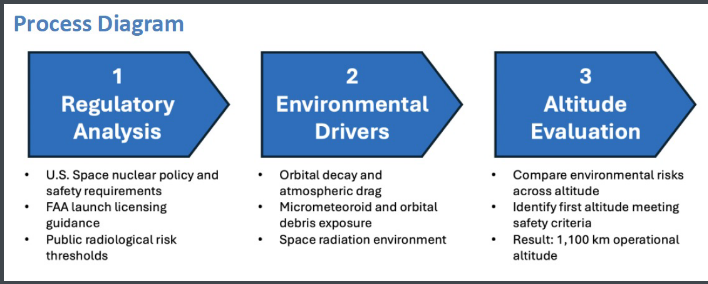
1. NRLMSISE-00 Atmospheric Model - empirical atmospheric density model used to estimate drag and orbital decay across altitude
2. NASA ORDEM / MMOD datasets - orbital debris flux and micrometeoroid environment data used to estimate impact probability by altitude
3. Space radiation environment datasets (OLTARIS/AP-8/AE-8) - radiation flux and dose models used to evaluate electronics survivability

Data Types and Format

Numeric, Spatial, Static, Structured

APPROACH

This thesis evaluates the altitude at which an NTP propulsion system can safely operate in Earth orbit prior to mission departure. The study first analyzes the modern U.S. regulatory framework governing space nuclear systems and launch safety. A representative NTP vehicle configuration and assembly timeline are then defined. Environmental conditions affecting on-orbit safety are modeled across altitude, including orbital decay, micrometeoroid and orbital debris exposure, and the space radiation environment, to identify the lowest altitude that satisfies regulatory safety requirements.



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IMPACT

The analysis identifies an operational altitude regime that satisfies the safety constraints governing U.S. space nuclear systems while remaining practical for mission design. The results show that approximately 1, 100 km is the first altitude at which the key environmental drivers of regulatory risk, orbital decay timelines, debris exposure, and radiation survivability, simultaneously meet safety expectations within the current U.S. licensing framework.

Below this altitude range, atmospheric drag significantly shortens orbital lifetime, increasing the likelihood of uncontrolled reentry over regulatory planning horizons. Higher altitudes provide longer passive orbital lifetimes but do not materially improve the safety factors evaluated in this study, while requiring greater launch energy to reach orbit. Because launch energy directly affects payload capability and mission cost, identifying the lowest altitude that satisfies safety requirements establishes the most economically practical operating region for commercial NTP systems.

These results give mission designers a defensible basis for planning Earth-orbit staging operations for nuclear propulsion systems under the modern regulatory environment. They also translate high- level U.S. policy and FAA safety guidance into practical design criteria for altitude selection.

Beyond the specific altitude identified here, the modeling structure can be applied to alternative vehicle designs, shielding strategies, orbital dwell times, and launch cadences. This provides future mission planners with a reusable analytical basis for evaluating orbital staging strategies and supporting early regulatory discussions.

DRIVERS	Renewed interest in Nuclear Thermal Propulsion for cislunar and deep-space missions has led to architectures that assemble propulsion systems in Earth orbit before departure. However, current U.S. regulations provide limited guidance on acceptable operational altitudes, creating uncertainty for mission designers and commercial operators.
BARRIERS	Key challenges included translating high-level regulatory guidance into quantitative design criteria and integrating multiple environmental risks into a single decision framework. Orbital decay, debris exposure, and radiation environments vary significantly with altitude and require different modeling approaches.
ENABLERS	This work was enabled by access to established environmental models and datasets describing atmospheric density, orbital debris flux, and the space radiation environment. Historical solar and atmospheric records, debris environment models, and radiation datasets allowed environmental conditions to be evaluated across orbital altitudes. Prior research on nuclear propulsion architectures and current U.S. regulatory guidance also provided the policy and technical context needed to structure the analysis.
ACTIONS	The project analyzed the modern U.S. regulatory framework governing space nuclear systems and launch licensing. A representative nuclear propulsion vehicle and assembly timeline were defined to establish consistent modeling assumptions. Orbital altitudes were evaluated through orbital decay modeling, debris exposure analysis, and radiation environment assessment to determine the lowest altitude that satisfies safety requirements.
INNOVATION	The project integrates regulatory policy with environmental modeling to inform a practical mission design decision. Rather than analyzing orbital decay, debris exposure, or radiation independently, the study evaluates these drivers together within the context of current U.S. licensing requirements. This provides a structured way to translate regulatory safety principles into operational design parameters for future nuclear propulsion missions.
IMPROVEMENT	The analysis identifies approximately 1, 100 km as the first altitude at which key environmental drivers of regulatory risk simultaneously satisfy safety expectations under the current U.S. framework. Establishing this threshold reduces design uncertainty for nuclear propulsion missions and provides mission planners with a defensible basis for selecting operational altitudes without unnecessarily increasing launch energy requirements.
BEST PRACTICES	Early integration of regulatory constraints into technical design analysis helps avoid costly redesign later in program development. Evaluating environmental risks across multiple drivers simultaneously also improves decision quality compared with treating individual factors such as orbital decay or debris exposure in isolation.
OTHER APPLICATIONS	The analytical structure developed in this work can be applied to other space systems that require extended residency in Earth orbit, including nuclear electric propulsion stages, reusable transfer vehicles, and large modular spacecraft assembled in orbit prior to departure for cislunar or deep- space missions.