UCRL--95301

DE87 008726

NUCLEAR SAFETY AS APPLIED TO SPACE POWER REACTOR SYSTEMS

G. E. Cummings

This Paper Was Prepared for Submittal To
4th Symposium on Space Nuclear Power Systems
Albuquerque, New Mexico
January 12 - 16, 1987

Lawrence Livermore National Laboratory

NUCLEAR SAFETY AS APPLIED TO SPACE POWER REACTOR SYSTEMS

Garth E. Cummings
Lawrence Livermore National Laboratory
P.O. Box 808, L-198
Livermore, CA 94550
(415) 422-4949

Introduction

Since the start of the current space power reactor development effort, it has been realized that safety must be a primary consideration (DOE, 1986). This concern for safety is driven to an extent by the publicity surrounding the unplanned reentry of two Soviet space power reactors, Cosmos 954 and 1402, and by the Three Mile Island 2 accident, even though this latter event has little relevance to space power reactor safety. In addition, concerns for safety were increased after the recent Challenger disaster and the Chernobyl accident. It is therefore incumbent on managers of space power reactor projects to not only design safety into their reactor systems but to be able to demonstrate to potential users and the public that safe designs have been achieved. This latter objective will be difficult, but possible to achieve, if we make full use of pertinent experience and demonstrably incorporate safety into our concepts and designs from the start.

To develop a strategy for incorporating and demonstrating safety, it is necessary to enumerate the unique aspects of space power reactor systems from a safety standpoint. These features must be differentiated from terrestrial nuclear power plants so that our experience can be applied properly. Some ideas can then be developed on how safe designs can be achieved so that they are safe and perceived to be safe by the public. These ideas include operating only after achieving a stable orbit, developing an inherently safe design, "designing" in safety from the start and managing the system development (design) so that it is perceived safe. These and other ideas are explored further in this paper.

Unique Aspects Of Space Power Reactor Systems

Space power reactors differ in many ways from the more familiar terrestrial based commercial power reactors. These differences must be understood so that past safety practice can be properly applied. Some of these differences have been tabulated in Table 1.

Since flight systems are only to be started once a stable orbit is achieved, no radiation will be present while the reactor is on the ground and throughout the launch phase. Accidents which could occur after launch would have minimum consequences since they would occur in space. This does not mean that accidents are of less concern, since radioactive debris could interfere with other operations, but that their direct consequences to the public would be minimal.

The small, compact design needed to minimize weight requires high temperature operation and materials of a very rugged and stable character. This maximizes both the ability of the reactor to withstand a launch accident and its ability to reenter the earth's atmosphere after it has operated and land intact without spreading radioactivity about. In addition, the small size of the reactor eliminates potential xenon stability problems,

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

even for a thermal neutron spectrum, and enhances the negative temperature coefficients of reactivity because of the sizeable neutron leakage effect. Xenon instability and positive temperature and void coefficients of reactivity are believed to have contributed to the Chernobyl accident. Table 2 gives typical temperature coefficients and their characteristics. The negative coefficient of space reactors is driven by core expansion with increasing temperature while the light water moderated reactors (LWR) have strong negative moderator coefficients due to moderator expansion. The graphite moderated RBMK-1000 reactors such as at Chernobyl have positive moderator coefficients and negative fuel (Doppler) coefficients (National Nuclear Corporation, 1975, 1986). Their transient behavior is aggravated by their positive void coefficient. Both space power reactors and LWR's have negative void coefficients.

Launch phase accidents with the shuttle point to concerns about inadvertent criticality or release of toxic materials used in the designs, e.g., beryllium. As stated above, the rugged design minimizes both these concerns but they still must be considered. Reentry is a unique safety concern for space power reactors. Current designs preclude dispersion in the upper atmosphere because of the refractory materials used so that intact reentry is currently the preferred mode. Thus, the radiation hazard after landing will be localized and thus minimized. Reactor designs must assure this.

Taking Into Account Public Perception

To overcome fears engendered by the Cosmos and Chernobyl experiences in addition to shuttle reliability concerns made visible by Challenger, current space power reactor designs must be made safe in such a way that they are perceived safe. This must be done while optimizing the design so as to produce a workable, reliable, and cost effective flight system. Sometimes these tradeoffs are not easy. For instance, an inadvertent criticality caused by water immersion following a launch ascent abort may not cause much of a radiation hazard but could be a public relations disaster. Design to preclude such an inadvertent criticality could cause severe constraints on the design if risk (real or perceived) is not properly balanced against benefit. Still, space power reactor designs must be perceived safe either by eliminating accident causes or effects or by demonstrating the risks are minimal compared to the benefit. An example of the latter trade-off is the premise that defense related missions be subjected to less stringent safety precautions because of the critical benefit gained.

An Approach To Safety

A rational approach to safety is possible and is reflected in the conduct of the current space power reactor projects (DOE 1982,1986). Such an approach requires an identification of the unique safety concerns associated with space power reactors, criteria establishing how these concerns should be alleviated, and a program to see that these criteria are satisfied by the designs. Both conceptual and prototype designs need to incorporate these criteria so that features are not locked in during the concept development phase that must be undone later. Backfits are expensive, disruptive and can be perceived as showing weakness in the design process.

Risk analysis techniques can be useful in comparing safety of alternate design features and in assuring that the risk is balanced across the design. To a lesser extent risk analyses can be used to show that accident risks are acceptably low although such quantification is subject to much uncertainty. Still, using risk analysis techniques assures a global, balanced view of safety and methods and experiences from the nuclear power industry can be used to good advantage.

Where possible, the assurance of safety should be designed in to provide an inherently safe design. An example would be to design the reactor so that under no circumstances will it go critical in water thus precluding an inadvertent criticality accident should the reactor crash in the ocean. Also, it might be possible in some of the lower power designs to provide enough external heat transfer area to prevent core melting in space after a loss of coolant. Such design features usually carry a weight or performance penalty and must be looked at closely.

Perhaps most important, a carefully designed experimental and review program must be established so that safety is clearly demonstrated. Since this can be an expensive undertaking, it needs to be established carefully, balancing performance and safety goals.

Conclusions

Recent occurences in the U.S. Space Shuttle and Soviet Nuclear Power programs have again emphasized the importance of safety to our current space power reactor projects. The course these projects have set regarding safety is the correct one but must be pursued vigorously with adequate funding and priority. Lessons learned from the commercial nuclear power experience can be useful such as in the use of risk assessments and safety goals. There are enough differences between commercial and space reactors to show that the problems of one do not preclude safe operation of the other. Still, if the current space power reactor projects are to enjoy continued public support, more attention to safety and how that is perceived will be needed than in past reactor development projects.

References

1. Safety Policy Statement for the SP-100 Ground Engineering System (GES) Program, U. S. Department of Energy, SP-100 GES Program, Office of Nuclear Energy, Germantown, MD, July 1986.

2. The Russian Graphite Moderated Channel Tube Reactor, National Nuclear Corporation Limited, Booths Hall, Knutsford, Cheshire, United Kingdom, NPC(R)1275, March 1975, May 1986.

3. Nuclear Safety Criteria and Specifications for Space Nuclear Reactors, U.S. Department of Energy, Office of Space Nuclear Projects, Germantown, MD, OSNP-1, August 1982.

4. SP-100 Ground Engineering Systems (GES) Project, Request for Proposal DE-RP03-8GSF16006, U.S. Department of Energy, San Francisco Operations Office, Oakland, CA, February 1986.

TABLE 1: UNIQUE ASPECTS OF SPACE POWER REACTOR SYSTEMS

- Negligible radiation hazard while on the ground. Operation will only commence after achieving a stable orbit.
- Accidents during operation would occur in space, minimizing any consequences.
- The small, compact design enhances reactor ruggedness and nuclear stability.
- Potential launch phase accidents need to be considered.
- Reentry hazards need to be considered.

TABLE 2: TYPICAL TEMPERATURE COEFFICIENTS OF REACTIVITY

Reactor Type	Approximate Overall Temperature Coefficient,/K	Characteristic
SP-100	-10^{-5}	Expansion is the main contributor to the coefficient.
LWR	-10^{-4}	Moderator has largest effect. Both moderator and fuel Doppler coefficients are negative.
RBMK-1000 (Chernobyl)	$+10^{-4}$	Negative fuel Doppler coefficient. Positive moderator coefficient.