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APPLICABILITY OF TRENDS IN NUCLEAR SAFETY ANALYSIS TO SPACE NUCLEAR POWER SYSTEMS

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Abstract

A survey is presented of some current trends in nuclear safety analysis that may be relevant to space nuclear power systems. This includes: lessons learned from operating power reactor safety and licensing; approaches to the safety design of advanced and novel reactors and facilities; the roles of risk assessment, extremely unlikely accidents, safety goals/targets; and risk-benefit analysis and communication.

INTRODUCTION

Safety in the use of space nuclear systems involves the management of risk for both the space and earth environments. Unlike most terrestrial nuclear energy sources, space nuclear systems are usually highly mobile which leads to a changing risk horizon. However, the source of radioactivity bears resemblance to terrestrial systems. Fission in space power or propulsion systems also obviously occurs in terrestrial power and research reactors. Similarly, the actinide decay power source of the radioisotope thermoelectric generator is also present in spent fuel. Energy conversion systems can be very different between the space and the more familiar land based systems, but the basic theme is the same. In both arenas there is a fundamental need to prevent accidental releases of radioactive materials to regions in which they can become a hazard to health and the environment. Thus it is worthwhile to consider how current approaches to safety analysis may be applicable to space nuclear systems.

Earth-based nuclear power systems are mainly associated with electricity generating units. In the U. S. there are approximately 100 units that are licensed to operate, and world-wide there are approximately 500 units. South Korea and Taiwan are experiencing a growth in their nuclear power industries while France, Germany, and Japan are endeavoring to maintain rather large programs against a backdrop of growing public opposition. In Eastern European countries and in the former Soviet Union there are many initiatives directed toward upgrading the safety of the various Soviet-designed reactors.

CURRENT TRENDS IN SAFETY ANALYSIS

The current fleet of power plants in the U. S. is aging and licensing renewal issues are receiving much attention, especially for the plants that have been in operation for more than twenty years. The current aging research program for nuclear power plants (Bosnak 1992) consists of three elements: select and prioritize components, systems, and structures for which aging must be managed; identify and understand the relevant mechanisms and their effect on performance; and take appropriate action to manage degradation through effective inspection, surveillance, condition monitoring, trending, preventive and corrective maintenance, and mitigation to prevent reduction in safety margins.

The effects of aging on the nine U. S. space nuclear systems that are currently in orbit has been recently assessed by Bartram and Tammara (1992). The potential mechanisms for radiological releases were identified to be: containment disruption from debris in orbit; reentry burnup; and land impact on rock surfaces. The radiological releases were based on expected orbital lifetime and radionuclide decay, assuming no retrieval of the nuclear power systems from orbit. Various material degradation modes were considered in determining the effects of aging on the fuel containment materials. With no intervention, the first reentry will occur in 130 years with a release of approximately 5000 Ci.

Aging of space nuclear power components, systems, and structures will need to be considered particularly for long missions and for systems that might be placed on other planetary bodies for long periods of time. Studies of the reliability and risk of systems that are influenced by aging are currently under way for land based power plants. It would be of value to any space program to be aware of the aging research that has been conducted so far and to make appropriate use of this information.

While new reactor orders have not been forthcoming in most countries, there are nevertheless several new reactor designs on the drawing boards. These designs introduce new safety features that require less operator intervention during an accident and are also aimed at being more cost-effective than their predecessors. With novelty in design comes the need to explore and evaluate the untested or unknown. For example, the reliance on decay heat removal by natural convection of the working fluid must be verified in terms of the specific elevations, flow paths and resistances, and heat sources and sinks that are all part of the heat removal scheme. Space nuclear power systems and these new designs have very limited operational data bases, particularly for integral effects. In both areas, separate effects tests and integral tests will contribute to the demonstration of safety of the proposed systems.

All of the new designs build on the concept of defense in depth in that they provide multiple barriers against the potential release of radioactivity that is normally contained in the fuel matrix. The concept of defense in depth is not new but the envelope of accidents that it applies to is derived somewhat differently now than in the earliest days of reactor safety. The earlier approach relied on a maximum accident for the definition of the envelope. Thus, for light water reactors this was the large break loss-of-coolant accident. However, probabilistic risk assessment taught us that the worst case initiator did not lead to the highest risk sequences when both probabilities and consequences were viewed in a broader context. These notions are now factored into the modern applications of defense in depth to new reactor designs. Undesirable accidents are either designed to have a low probability or low consequences (or both).

Current approaches to safety do not limit defense in depth concepts to just the design of a nuclear system. Rather, it is extended to the operational and emergency related activities for a facility. One can regard the management of safety and risk in terms of three components: reliability management; accident management; and emergency management. Reliability management refers to the design and operation of a facility. Emphasis is given to the incorporation of safe design features and operational procedures. Data from testing and operational experience are continuously used to maintain a high level of performance of the facility. Accident management refers to the set of activities that would be taken by the facility operation and/or management team to control the outcome of an abnormal event at the earliest possible time and with the minimum adverse consequences. Emergency management refers to decisions and actions that are taken to protect the health of the public and the environment from the potential or actual accidental releases of radioactive material from the facility.

These concepts carry over to the space nuclear enterprise as well. Clearly, any space nuclear effort will need a good reliability program and there should be plans in place to deal with emergency situations. The counterpart of accident management for space nuclear systems will depend upon whether a mission is manned or unmanned. For unmanned missions, accident management would have to be done remotely and possibly over very large distances which could involve time delays in transmission and receipt of signals. For manned missions, the crew could play a hands-on role in accident management. Particular attention would be given to crew safety and to assuring that the spacecraft does not become impaired as a result of the accident conditions. The new land based power reactor designs also rely on passive safety systems that would be highly reliable under accident conditions. This is an area of current research that could also be of benefit to space nuclear power.

LESSONS LEARNED

Perhaps the most important lesson learned from the safety review and licensing process for land based power plants is that the process is far more complex than initially anticipated and unexpected events can greatly influence the outcome. Many interested parties participate in this process including federal, state, and local governments, as well as special interest groups. All must be taken seriously as the process evolves. Communication of safety and risk is a difficult process and this information must be conveyed in an understandable way. In addition, benefits and the risks of not pursuing a particular option must also be understood by all parties.

Probabilistic risk assessment has proven to be an important and effective tool for identifying design vulnerabilities and in improving operational activities. Much insight has been gained by the designers, operators, and regulators from probabilistic risk assessment. While bottom line risk numbers from a probabilistic risk assessment could be compared with safety goals or targets, it is also recognized that these numbers are uncertain because they suffer from incompleteness and inaccuracy in scenario identification, data base, and modeling. It is nevertheless the quantification process of the probabilistic risk assessment that leads to the separating of the important from the unimportant and to the development of safety insights.

Probabilistic risk assessment methods have also proven to be valuable in the management of risks posed by nuclear facilities. The recent topical conference on Risk Management (1992) provides an excellent survey of state-of-the-art applications of this important tool.

As suggested above, risk communication is an area that is not as well developed as risk assessment or risk management. A panel of the National Research Council (1989) identified research needs in this area. It is interesting to note that as one moves from risk assessment to risk management and then to risk communication, the main focus of the discipline shifts from the technical sciences to the social sciences. All are important for the success of both land based and space nuclear power programs.

SUMMARY

A survey has been presented of some current trends in nuclear safety analysis that may be relevant to space nuclear power. The main purpose here was to keep this information in focus for the space nuclear safety program so that it might benefit from some insights and techniques that are part of the broader nuclear safety field.

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