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ACCIDENT SEQUENCE MODELING FOR RADIOISOTOPE POWER SYSTEMS. D. J. Clayton[1], G. M. Lucas[2], T. E. Radel[3] and B. D. Wiberg[4], [1]Sandia National Laboratories, Mail Stop 0747, P.O. Box 5800, Albuquerque, New Mexico 87185. djclayt@sandia.gov. [2]Sandia National Laboratories, Mail Stop 0747, P.O. Box 5800, Albuquerque, New Mexico 87185. glucas@sandia.gov. [3]Madison, WI 53701. teradel@yahoo.com. [4]Utah State University, ENINV 310A, 4100 Old Main Hill, Logan, UT 84322. brockwiberg@gmail.com.

Introduction: For fifty years nuclear power sources have enabled exploration missions in deep space and locations where solar panels are impractical or inefficient. As compact and light weight power sources with reliable and long lives, Radioisotope Power Systems (RPSs) have extended our knowledge of the solar system [1]. Due to the hazardous material that can be released during a launch accident, the potential health risk of an accident must be quantified. It is the responsibility of the RPS Launch Safety (RPSLS) group to accurately quantify this risk so that appropriate launch approval decisions can be made. The RPSLS group works to take mission information and experimental data and produce formal reports which describe mission risks. RPSLS seeks to constantly improve the precision and accuracy of these risk estimations. The risk estimations compare the potential risks involved with the probability of occurrence.

One part of the risk estimation involves modeling the response of the RPS to threatening environments that result from accidents during the mission. Figure 1 shows some possible accident scenarios. The figure shows that the RPS response is highly dependent on the time when an accident occurs. The time will determine the possible impact surfaces and velocities, as well as the local environment, such as blast overpressure and fragment impacts.

Computer Modeling: The simulation of the RPS response to the accident environments is embodied in a computer code entitled Launch Accident Sequence Evaluation Program (LASEP) [2]. The location and state of the RPS is simulated from the initial insult, generally occurring at-altitude, through Earth impact and any subsequent thermal environments associated with the accident. The outcome of the simulation in-

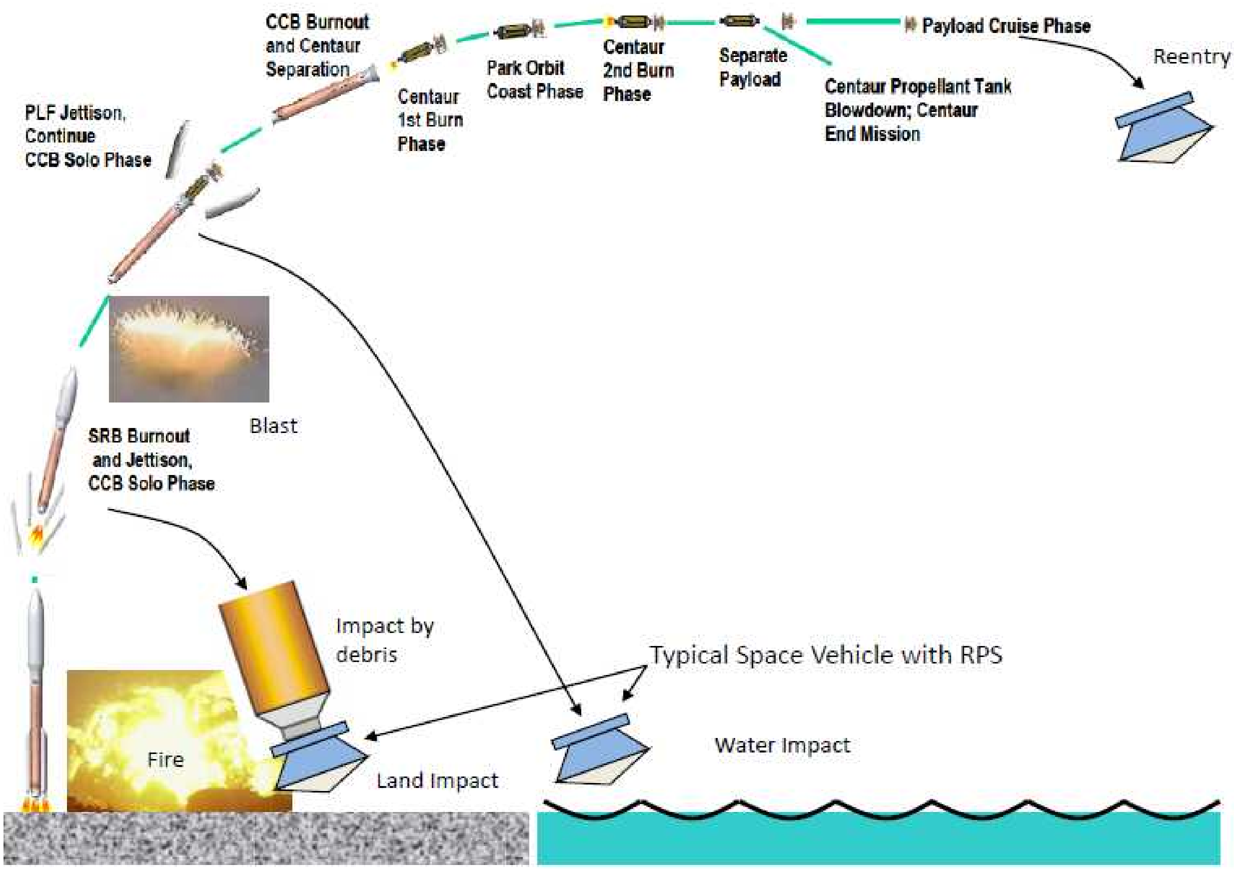

Figure 1. Possible accident scenarios

volves determining whether a release of hazardous material occurs and, if so, the characteristics of the release, which include the release's mass, location, and particle size distribution.

LASEP performs the simulation by modeling the numerous environments resulting from a particular accident. An accident initiating condition (AIC) represents the first point of departure from the nominal mission sequence leading to a subsequent accident outcome condition (AOC). The AOC may occur instantaneously with an AIC, or at any time thereafter.

The first potential threat to the integrity of the RPS occurs at the AOC. At this point in the accident event sequence, the models of at-altitude environments must be applied to determine the state of the RPS and its components. The typical sequence for these environments is a blast overpressure, followed by a fragment field, and lastly a fireball. The blast overpressure depends on the altitude of the event, which is derived at the AOC and the amount and location of propellant from the launch vehicle. The fragment field defines the mass, dimensions, origin and velocity of the fragments. The fragment properties are dependent on the blast and AOC. The resulting fireball is calculated based on the amount and types of fuel remaining in the launch vehicle. The size and type of fireball affects the particle size distribution and the amount of material that is vaporized.

After the at-altitude environment models have been applied and the state of the RPS has been determined, the next element of the sequence is to determine the RPS's flight to the ground, which either involves a space vehicle-RPS combination or a separated RPS that falls independently. The trajectory of each of the fragments is also determined. The fragment field is then evaluated to determine if there was an impact with the RPS during the flight to the ground.

At the time of ground impact, the models of ground impact environments must be applied. The effect of the ground impact is dependent on the impact orientation of the RPS and the impact surface. The RPS may then be impacted by falling debris. For accident scenarios where the liquid propellant does not ignite in the air, ground fires, along with blast overpressures are calculated. Some accidents will require application of a model to determine the effects of solid propellant impacts and fires when fragments of the solid propellant land in proximity to the RPS and RPS components. The solid propellant fire will also impact the particle size distribution and amount of material that is vaporized.

As events occur, the accident environment is determined and the resulting damage is calculated. Damage can be caused by many insults. As the accident scenario progresses, the quantity and particle size distribution of released material from each insult is calculated. While many insults result in no release of material, their cumulative effect may result in a release.

Statistical Analysis: Due to the complexity of modeling the full RPS response deterministically on dynamic variables, the evaluation is performed in a stochastic manner with a Monte Carlo simulation. A Monte Carlo simulation involves drawing random numbers from a probability distribution in order to model a process whose evolution is a sequence of states determined by random events. By repeating the simulation many times, one may apply general statistical measures to the results to determine expected outcomes, probabilities of various outcomes and a measure of the uncertainty of the calculation.

The model is executed many times to accurately characterize each accident scenario. Each execution cycle, which simulates the occurrence of a single accident, is called a trial. Within an accident scenario, results for each trial are independent because a new set of random numbers is generated for each trial. A large number of the simulations can result in no release. By gathering statistics on the outcomes for all trials, the probability of release and the distribution of releases for each accident scenario according to geographic location, altitude, particle size, and total mass can be estimated. This information is then used to inform decision makers of the potential health risks resulting from the use of nuclear power sources for space missions.

References:

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[2] Radel T. E and Robinson D. G. (2008) "Launch Safety Analysis Code for Radioisotope Power Systems," Proc. PSA 2008, Knoxville, Tennessee, Sept. 7-11, 2008, American Nuclear Society.

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